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CORRECTION

MONTHLY WEATHER REVIEW, January 1944, vol. 72, No. 1, p. 1: Near the bottom of the first column, in the first expression for I, the factor 10 in the denominator should be 10^4 and the subscript to the First V should be z_0 so that the equation reads

$$I=(V_{z_0}\rho_{w_0}-V_{z_1}\rho_{w_1})\frac{3600}{10^4}\times 0.3937$$

Near the bottom of the second column, in the final expression for I, $\rho 0$ should be replaced by ρ_0.

DEPARTMENT OF COMMERCE
CHARLES SAWYER, Secretary

WEATHER BUREAU
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FORECASTING THE PASSAGE OF SELECTED SOUTHWARD-MOVING COLD FRONTS IN SUMMER AT WASHINGTON, D. C.

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[Manuscript received June 16, 1950; revision received January 9, 1952]

ABSTRACT

Cases are selected which are thought to present the summertime problem of whether a cold front will pass Washington, D. C., from the north "tomorrow". Variables that measure the effective steering direction at 700 mb., the strength of zonal current at 700 mb., and the availability of cold air in Canada are found to be helpful in separating cases of effective frontal passage from other cases. The variables are combined in scatter diagrams to provide a systematic aid to forecasting the passage of the selected cold fronts.

INTRODUCTION

One of the more difficult forecasting problems along the east coast of the United States during the summer months is the forecasting of the maximum temperature at a given location for the following day, particularly during spells of hot weather when the public is seeking relief from the heat. An incorrect forecast of either continued hot weather or for cooling relief is widely publicized and results in considerable adverse criticism of the forecast. The success of a temperature forecast under these circumstances usually depends on the accuracy with which the movement of a threatening cold front is forecast. This study was undertaken with a hope that reliable criteria for frontal passage in summer could be established which could be applied by the forecaster to the data available up to 0130 EST when issuing a forecast of whether cooler temperatures can be expected at Washington, D. C., on the following day. However, the procedure which is developed applies only in the event that a front exists near or south of Sault Ste. Marie, Mich., but not south of Albany, N. Y. As will be made clear in the following section, there are certain types of frontal passage that are not included here due to the particular time lag selected for study and other reasons, but it is believed that the results will provide a useful guide when used as specified.

SYNOPTIC ASPECTS OF THE PROBLEM

The main criterion for the passage of a cold front from the north or northeast *at or near the time of passage* was found by Hoover and Sanders [1] to be the presence of a High with a central pressure of at least 1020 mb. (sea level) behind the front to the north of Washington. To be of use in the 24–42 hour forecasts considered here, this and other criteria discussed by them would require a 24-hour forecast of the pressure pattern, and this in many cases would require a forecast of substantial anticyclogenesis over the period. The present study therefore was undertaken looking to the possibility that the criteria for the passage of the front with its resultant cooling could be isolated directly by the forecaster from the 0130 EST map of the day previous to the passage. Thus the criteria as of this time will consist largely of factors tending to describe the availability of the cold air in Canada and the flow necessary to move the cold air from Canada to Washington.

It was assumed at the outset of this investigation that there exist certain types of situations wherein a cold front passage from the west and northwest can be predicted by straightforward computation, examination of the number of isobars crossing the front, etc. These types are not considered here. A more difficult problem is posed however by situations such as those illustrated in figures 1 and 2 in which the forecaster might justifiably and correctly predict that on the following morning the front would be lying with an east-west orientation through Pennsylvania. The forecast of further southward movement of the front however becomes more difficult and it

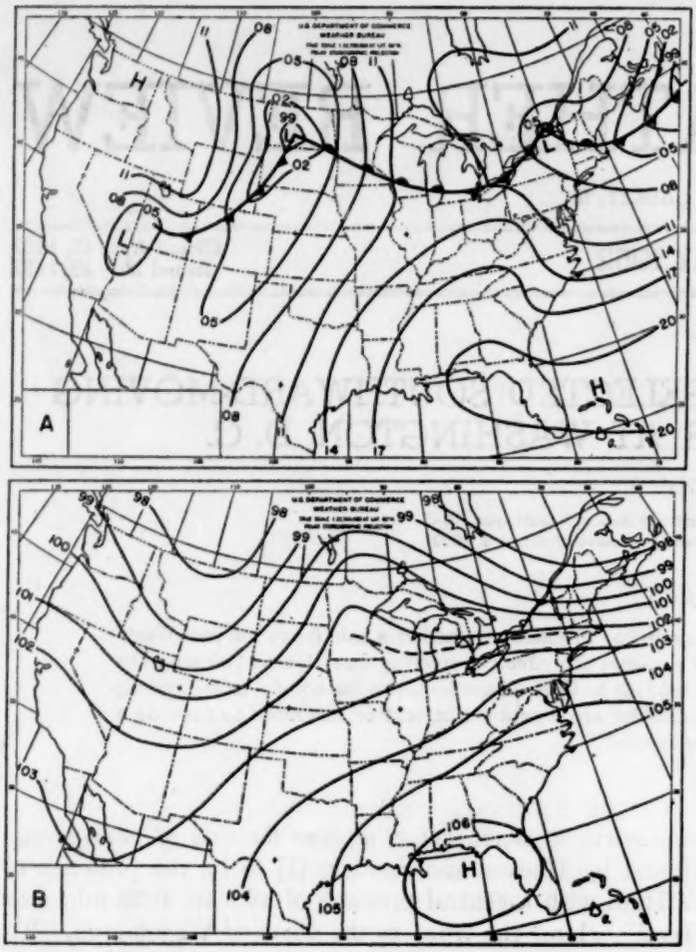

FIGURE 1.—Case 15 of table 1. (A) Sea level weather map for 0130 EST, June 27, 1949. (B) 700-mb. chart for 2200 EST, June 26, 1949.

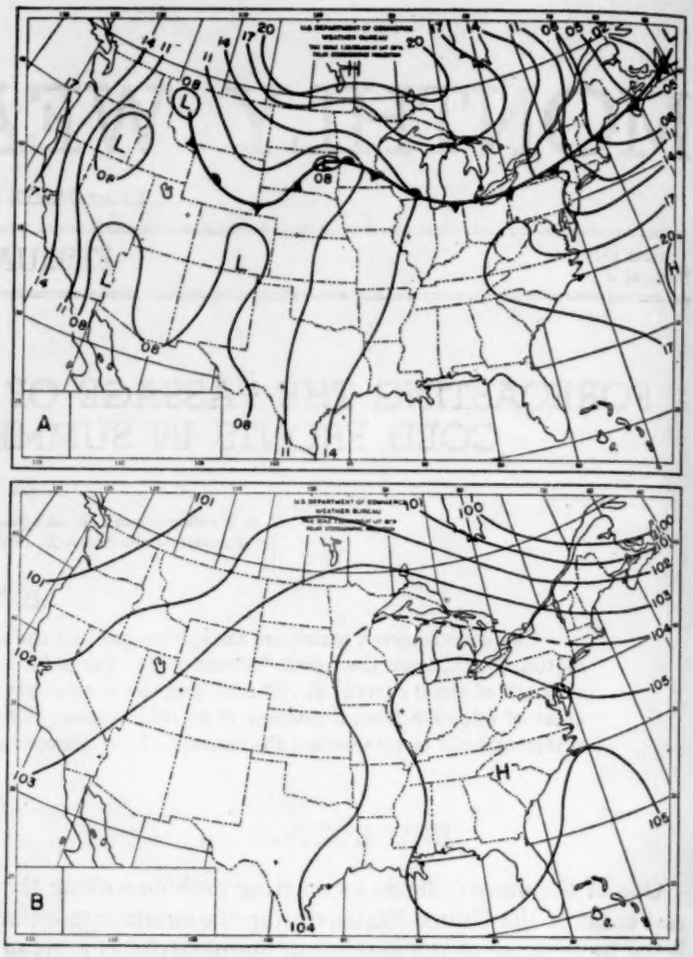

FIGURE 2.—Case 16 of table 1. (A) Sea level weather map for 0130 EST, July 5, 1949. (B) 700-mb. chart for 2200 EST, July 4, 1949.

is this and similar types of situations which have been selected for study at this time.

A preliminary examination of all 0130 EST maps for June, July, and August 1948 revealed 10 cases wherein this problem was posed. Examination of these cases, keeping in mind that the criteria should attempt to describe not only the availability of the cold air, but also its subsequent movement, showed a promising line of attack through the use of the following parameters:

1. The temperature difference at 700 mb. between Minneapolis-St. Cloud, Minn., and Churchill, Manitoba.
2. The temperature difference at 700 mb. between Albany, N. Y. and Moosonee, Ontario.
3. The temperature at 700 mb. over Moosonee.
4. The position of the 700-mb. height contour through Minneapolis-St. Cloud, Minn. relative to Toledo, Ohio and Albany, N. Y.

Factors 1 through 3 will be seen at once to be those selected to describe the potential availability of cold air in Canada. Factor 4 was then chosen as one which might describe the 700-mb. flow, within the type of situation studied, to determine the possibility of the steering of the cold air toward Washington in a manner described by George [2]. In all cases included in this study, the High considered was usually centered west of Moosonee and the front generally near (i. e. approaching or south of) Sault Ste. Marie but not south of Albany. In cases wherein the High is east of Moosonee *and* the front south of Albany, the problem is more apt to be that of whether the front will pass "today" and is not discussed in this report.

DEVELOPMENT OF FORECASTING PROCEDURE

Following the preliminary selection of the parameters outlined in the preceding section, the indicated data were extracted from all 2200 EST 700-mb. charts for the months June, July, and August 1947, 1948, 1949, for those cases wherein an inspection of the accompanying 0130 EST surface chart indicated the possibility of the southward passage of a cold front "tomorrow". Table 1 is a catalog of all cases treated in the study including those selected from the summer of 1947.

As the study progressed it was felt that a more tangible measure of the flow east of Minneapolis could be obtained through the use of the latitude at which the 700-mb. contour through Minneapolis intersected the 75th and

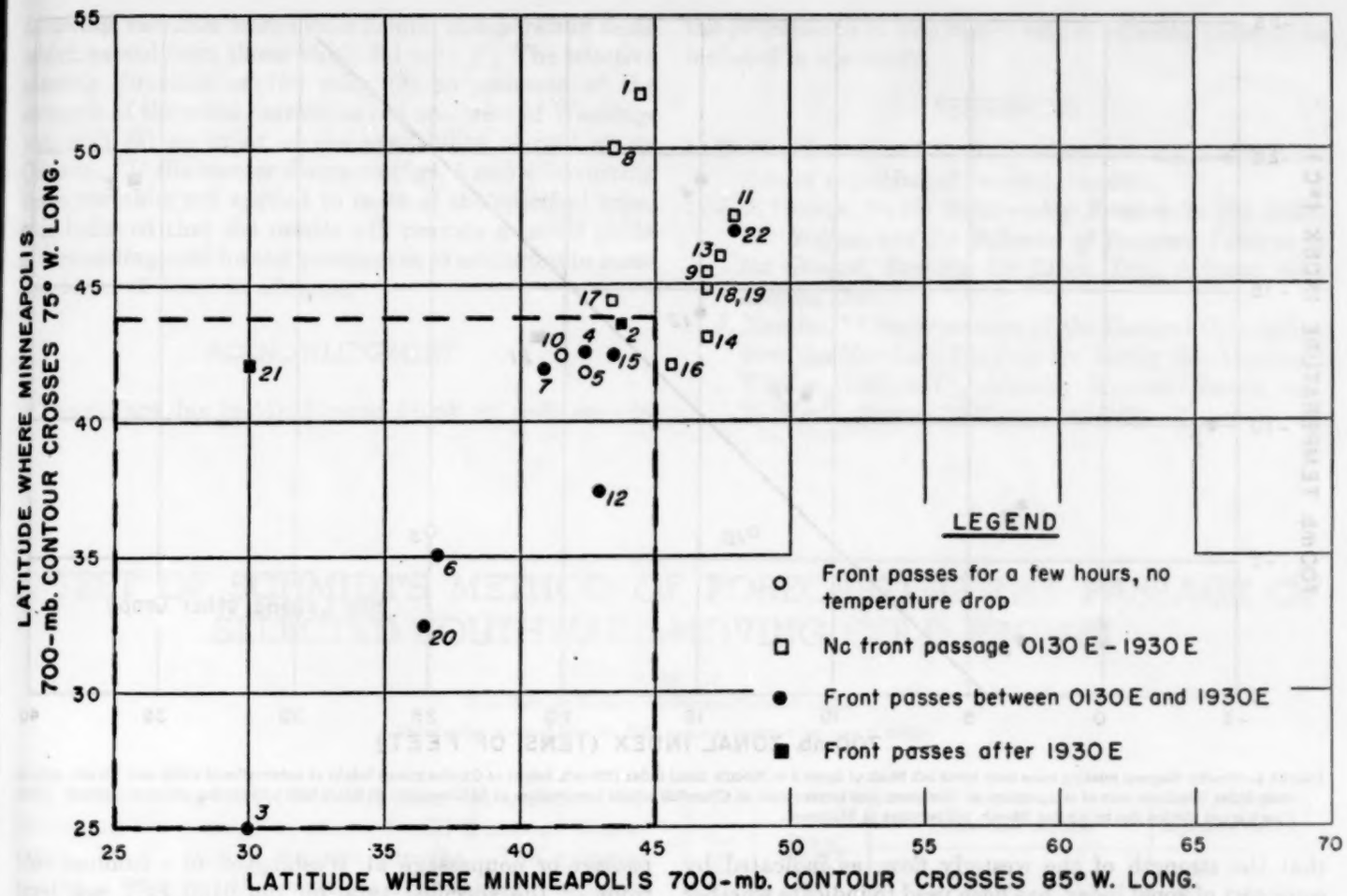

FIGURE 3.—Scatter diagram relating cases in table 1 to latitude at which the 700-mb. height contour through Minneapolis crossed 75° W. and 85° W. longitude 28 hours before beginning of forecast period, 0130–1930 EST. The block in the lower left separates cases of frontal passage from those of no frontal passage.

TABLE 1.—*Catalogue of cases used in developing forecast procedure*

Case No.	Date of 2200 EST 700-mb. chart	Independent variables *				Dependent variable **
		1	2	3	4	5
1	Aug. 14, 1947	44.5	52.0	−10	25	X
2	Aug. 27, 1947	44.0	43.5	−19	36	L
3	June 3, 1948	30.0	25.0	−7	3	P
4	June 14, 1948	42.5	42.5	−19	15	P
5	June 24, 1948	42.5	42.0	−6	25	I
6	July 5, 1948	37.0	35.0	?	7	P
7	July 12, 1948	41.0	42.0	−10	−4	P
8	July 17, 1948	43.5	50.0	−6	21	X
9	July 20, 1948	47.0	45.5	−12	4	X
10	July 27, 1948	41.5	42.5	−6	13	I
11	Aug. 25, 1948	48.0	47.5	−7	5	X
12	Aug. 29, 1948	43.0	37.5	−14	15	P
13	June 11, 1949	47.5	46.0	−10	10	X
14	June 18, 1949	47.0	43.0	−13	16	X
15	June 26, 1949	43.5	42.5	−11	11	P
16	July 4, 1949	45.5	42.0	−16	1	X
17	July 19, 1949	43.5	44.5	−7	28	X
18	Aug. 8, 1949	47.0	45.0	−9	12	X
19	Aug. 10, 1949	47.0	45.0	−10	7	X
20	Aug. 17, 1949	36.5	32.5	−2	3	P
21	Aug. 22, 1949	30.0	42.0	−13	21	X
22	Aug. 18, 1947	48.0	47.0	−6	13	P‡

* Independent variables:
1. Latitude at which 700-mb. contour through Minneapolis crosses longitude 85° W.
2. Latitude at which 700-mb. contour through Minneapolis crosses longitude 75° W.
3. Moosonee 700-mb. temperature plus Churchill 700-mb. temperature minus Minneapolis 700-mb. temperature.
4. 700-mb. zonal index: Omaha 700-mb. height minus International Falls 700-mb. height.

** Dependent variable:
5. Passage during forecast period.
P = Definite passage at Washington.
X = Definitely does not pass.
L = Passes after forecast period.
I = Ineffective passage for short time.

‡ Front passed near end of forecast period.

85th west longitude meridians. Therefore this item is shown in the catalog rather than item 4 of the preceding section.

Figure 3 is a scatter diagram showing whether a front passage occurred at Washington during the period beginning at 0130 EST and ending at 1930 EST on the following day as a function of the parameters selected to describe the 700-mb. contour through Minneapolis. In this figure it will be seen that all of the actual passages during the specified period occurred when the flow, as indicated by the contour through Minneapolis, intersected the 85th meridian south of 45° N. and the 75th meridian south of 43.5° N.

However within this area, which is outlined by heavy lines on the chart, there exist two cases in which the front did not pass until after 1930 EST on the following day, plus two more cases in which the front actually passed, but only for a few hours and without any change to cooler weather. An attempt was then made, without success, to separate these four cases from the others by means of the temperature parameters indicated by items 1–3 in the preceding section.

At this point, some thought was given to the problem of why, under otherwise similar circumstances, the cold air moves southward or does not. When it was recalled

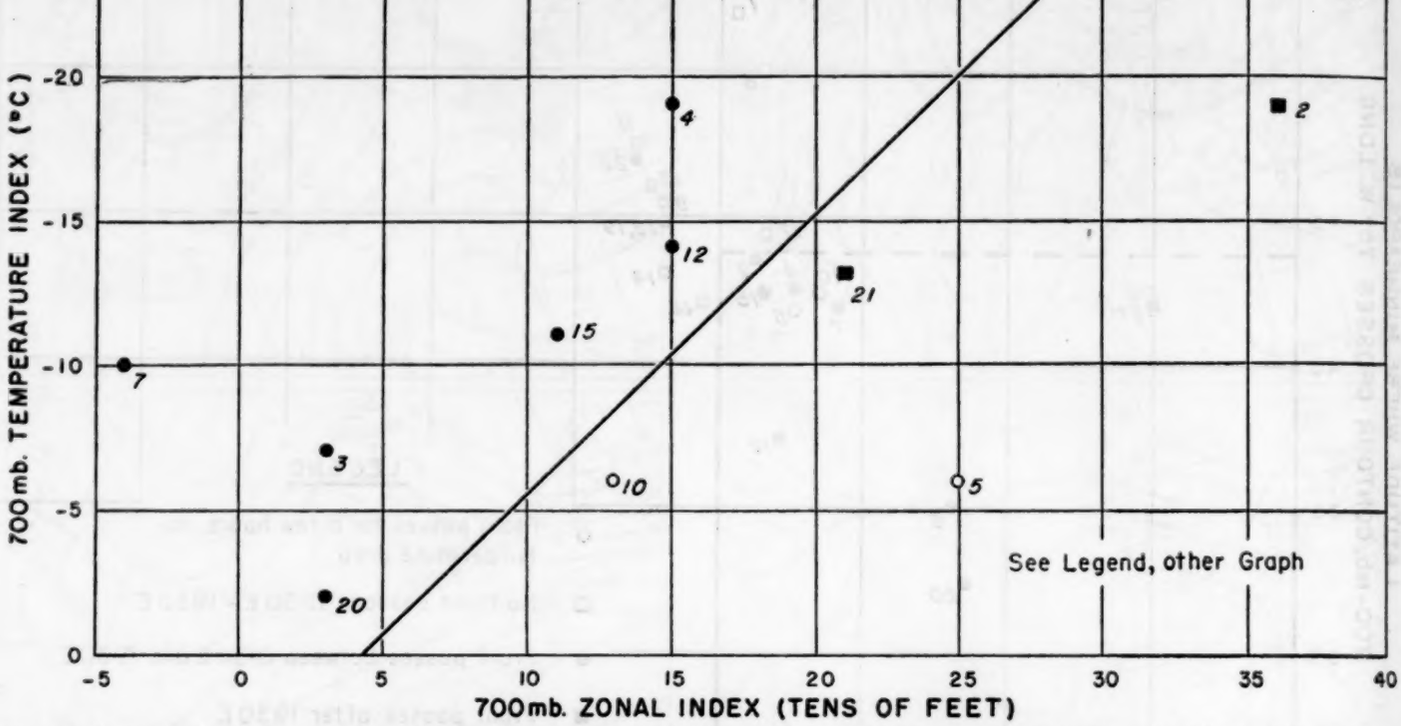

FIGURE 4.—Scatter diagram relating cases from lower left block of figure 3 to 700-mb. zonal index (700-mb. height at Omaha minus height at International Falls) and 700-mb. temperature index (algebraic sum of temperature at Moosonee plus temperature at Churchill minus temperature at Minneapolis) 28 hours before beginning of forecast period. Note: Case 6 is not plotted due to missing 700-mb. temperature at Moosonee.

that the strength of the westerly flow, as indicated by some sort of zonal index, has been used to indicate whether or not cold air could be expected to move southward (c.f., Namias [2]), a factor of this type was tabulated and tested. The strength of the flow was, in this problem of forecasting a day ahead, estimated somewhat to the west of Washington and at 700 mb. by taking the difference between the heights of the 700-mb. surface at Omaha and International Falls.

It was soon found that this variable was producing some of the desired separation, in that in only one case when the difference was 150 feet or less among the cases studied, did the front fail to pass decisively. It was then thought that this variable, along with a measure or index of the cold air to the northward would produce jointly a better separation than either could produce alone. An arbitrary temperature index was obtained by adding algebraically the 700-mb. temperature at Moosonee plus 700-mb. temperature at Churchill minus the 700-mb. temperature at Minneapolis. This temperature index was plotted against the Omaha-minus-International Falls "zonal" index in figure 4. A line is sketched which separates all cases of outright frontal passages from those which passed after 1930 EST or passed for only a few hours without lowering the temperature.

USE OF THE CHARTS FOR FORECASTING

With the aid of the 2200 EST 700-mb. chart and the scatter diagrams (figs. 3 and 4) which have been developed, passage or nonpassage at Washington of a summer cold front of the specified type on the 0130 EST sea level map may be rapidly forecast as follows:

1. Enter figure 3 with the appropriate coordinate values. Front is forecast not to pass in the specified forecast period unless the Minneapolis-St. Cloud 700-mb. contour crosses the 85th meridian south of 45°N. and the 75th meridian south of 43.5°N. If the plotted point falls in the block in lower left portion of diagram, the front is forecast to pass Washington and figure 4 then is checked for effectiveness of the passage during the forecast period.
2. If the case in question falls in the lower left block of figure 3, enter figure 4 to determine whether front will go sufficiently far south and remain long enough to bring in cooler air. The sloping line on figure 4 divides the effective fronts from those that are ineffective or pass after the end of the forecast period. For all cases which fall to the *left* of the sloping line, effective frontal passages are forecast.

CONCLUSIONS

In connection with the summertime problem of whether a front will pass Washington, D. C. from the north "tomorrow" (0130 to 1930 EST) a number of cases have been selected which were thought to present the problem. The

following variables were found helpful in separating those which passed from those which did not: (1) The effective steering direction at 700 mb.; (2) an estimate of the strength of the zonal current at 700 mb. west of Washington; and (3) an index of the availability of cold air in Canada. If the scatter diagrams (figs. 3 and 4) involving these variables are applied to cases of the specified type, it is believed that the results will provide a useful guide in forecasting cold frontal passages at Washington in summer 24 to 42 hours in advance.

ACKNOWLEDGMENT

Thanks are due to Mr. Conrad Mook for assistance in the preparation of this report and in selecting cases to be included in the study.

REFERENCES

1. E. W. Hoover and R. A. Sanders, private communication of unpublished research results.
2. J. J. George, *On the Relationship Between the 700 Millibar Surface and the Behavior of Pressure Patterns at the Ground*, Eastern Air Lines, Inc., Atlanta, Ga., August 1949.
3. J. Namias, "Characteristics of the General Circulation over the Northern Hemisphere during the Abnormal Winter 1946–1947", *Monthly Weather Review*, vol. 75, No. 8, August 1947, pp. 145–152.

A TEST OF SCHMIDT'S METHOD OF FORECASTING THE PASSAGE OF SELECTED SOUTHWARD-MOVING COLD FRONTS

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[Manuscript received May 24, 1951; revision received January 9, 1952]

In the foregoing study, Schmidt describes a method for forecasting the passage of selected cold fronts at Washington, D. C., during summer months. The summer months of 1945 and 1946 were set aside for test purposes, but due to the lack of a completely objective description of the type of situation described in the report, it was felt that such testing upon independent data should be left to someone other than the originator of the method.

The present writer, though perhaps not qualified to act as a completely independent judge of this technique since he helped select the cases in the original study, has undertaken such a test and suggests that others may wish to run the same experiment after reading Schmidt's paper and compare the results with those shown here. Altogether during the examination of all 0130 EST maps for June, July, and August of 1945 and 1946, seven cases were found which fit the definition of the type of situation to which this aid is applicable.

The following table lists the seven cases along with the data which are required for the test. The legend is the same as that shown above in Schmidt's table 1, except that column 5 contains the forecast and column 6 states whether or not an "effective" frontal passage occurred.

Though there may be some question as to the advisability of including case 6, it appears to be one in which a forecaster could logically attempt to apply the method. The question of a frontal passage at Washington must be considered in making the forecast and the decision to include it here is based largely upon the rapid eastward movement of a Low in the northern Great Lakes region. Such movement made it appear that future southward movements of the cold air would occur behind the Low as it moved *east* of the Lakes, and that the cold front would approach Washington from the north rather than from the northwest or west.

Test case No.	Date of 2200 EST 700-mb. chart	Independent variables				Dependent variable	
		1	2	3	4	Forecast 5	Observed 6
1	July 20, 1945	46.5	41.0	-------	-------	X	X
2	Aug. 17, 1945	36.0	38.0	−6	12	I	(*)
3	Aug. 28, 1945	45.0	45.0	-------	-------	X	X
4	June 6, 1946	46.0	43.0	−27	36	X	X
5	June 23, 1946	45.5	45.0	-------	-------	X	X
6	July 13, 1946	43.5	42.0	−24	28	P	P
7	Aug. 16, 1946	42.5	40.0	−11	9	P	P

* The front in question underwent frontolysis, so possibly the fact that an effective frontal passage was not forecast and none occurred justifies a statement that a correct forecast was made.

In general all of these forecasts are correct and therefore it appears that the method can be relied upon for use under the circumstances for which it is designed. However, these results are not intended to convey the impression that similar accuracy will be possible at all times, since one should expect an occasional error to occur due to unusual developments, etc., which have not occurred within the periods covered. Furthermore, one must point out the fact that there are some "back door" frontal passages at Washington for which the antecedent conditions differ from those specified by Schmidt. The method and the test are applicable under a particular set of conditions which, according to Schmidt, often precede by approximately one day the passage of southward-moving cold fronts at Washington, D. C.

SUMMER TEMPERATURES IN THE UNITED STATES

ARNOLD COURT

Office of The Quartermaster General,[1] Washington, D. C.

[Manuscript received August 21, 1951]

ABSTRACT

Percentage frequencies of hourly temperatures above certain values from 40° to 110° F., by 5° intervals, are presented for 102 places in the United States in summer (June-July-August). The frequencies are based on hourly readings, generally at airways weather stations, during five years 1935–1939. Since average summer temperatures during this period were somewhat warmer than long-term "normals," the resulting tabulation is considered applicable to a "typical warm summer" such that only about 15 summers per century would be warmer. The percentages are presented in a table, and those for temperatures above 85° (30° C. or higher) are shown on a map to indicate the regions where refrigerated storage is desirable for chocolate candy, which turns white ("graying" or "blooming") as soon as its temperature exceeds 85°.

INTRODUCTION

Summer temperatures in the United States, when described by the percent of hours expected to be above various values, can be used in quantitative estimates for such purposes as air conditioning and refrigeration not possible from the generally available averages and extremes. To obtain these percentage frequencies, hourly temperatures during five years in the United States were summarized and analyzed.

The basic observations were the hourly readings of wet and dry thermometers at airways weather stations, during 5 years (1935–39). These were tabulated and summarized by the Weather Bureau, through the Works Progress Administration, at the request of the American Society of Heating and Ventilating Engineers. Six separate summaries were made: air temperature, dew point, wet-bulb temperature, and correlations of air temperature with wet-bulb depression and of air temperature with wind speed. These six summaries are available on microfilm,[3] and portions of them have been used extensively in various studies [1, 2, 3]. Only the first of these summaries, for air temperatures, was used for the present study.

Of the 117 stations in the original tabulation, 15 were discarded because they had less than 10,000 of the 11,040 hourly observations possible during the 5 summers. The 102 remaining stations are generally distributed along the civil airways which had scheduled night-time flights during that period, so that the coverage of the United States is not uniform. From the original tabulation, which gave the frequencies of observations by each hour of the day for each month, the monthly totals for the three summer months were combined and reduced to percentages, shown in table 1.

DISCUSSION

Table 1 gives the percent of all hours during June, July, and August, 1935–39, on which temperatures at each of the 102 places, in 40 states and the District of Columbia, were above certain values from 40° to 110° F., by 5° intervals. The five summers, 1935–39, the period of observations on which the table is based, were slightly warmer than the long-term averages for the United States. For each of the 102 stations, average summer temperatures for those five years were computed and compared with the "normals" for the same places, as shown in the Weather Bureau's latest (1950) Climatological Data for the United States, by Sections. For a few of the places, such as El Morro, N. Mex., and Arlington, Oreg., detailed climatic data were not available, and the comparision was based on nearby stations with long records.

For the United States as a whole, a separate study not yet completed, indicates that the standard deviations of mean monthly temperatures in summer vary from nearly 4° in the Great Plains to less than 1° along the southern coasts, with the nationwide average about 2°. Since average monthly temperatures in general follow the "normal" distribution of statistical theory, it appears that for the United States as a whole about two summers out of three have average temperatures within 2° of the long-term averages, and only about one summer in six is more than 2° warmer than those averages.

During 1935–39, the average of summer temperatures at the 102 places for which frequencies are shown in table 1 was 1.8° warmer than the long-term "normals."

[1] Published with the approval, but not necessarily the endorsement, of the Department of the Army.

[2] Present address: 1520½ Spruce St., Berkeley 9, Calif.

[3] Information concerning these tabulations and their availability may be secured by addressing Chief, U. S. Weather Bureau, Washington 25 D. C., Attention: Climatological Services Division.

TABLE 1.—*Percent of hours in summer (June-July-August) with temperature above indicated values. (First column shows total number of hourly readings, 1935–39 inclusive, used)*

		40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°
Alabama																
Birmingham	11,038				99.9	99.2	97.0	86.3	58.0	28.1	21.9	8.3	1.7	1.7	0.1	
Mobile	11,036					99.9	99.7	96.1	73.1	42.5	22.4	5.4	0.7	(*)		
Arizona																
Kingman	11,029		99.9	99.6	98.7	96.5	92.2	80.8	65.8	50.8	36.6	23.2	9.7	.1		
Phoenix	11,032				(#)	99.6	98.3	94.3	87.8	75.1	59.8	46.0	31.9	17.8	5.9	0.6
Tucson	10,993			(#)	99.9	99.6	98.2	93.1	88.5	61.2	45.8	31.0	17.0	4.6	.3	
Winslow	11,014		99.8	99.1	97.1	92.2	81.6	65.1	50.3	36.6	23.2	10.8	2.6	.1		
Arkansas																
Little Rock	10,825				(#)	99.6	97.7	89.5	66.0	45.7	30.3	16.3	5.5	.7	(*)	
California																
Bakersfield	11,019			(#)	99.7	98.4	93.6	83.7	71.1	57.3	43.2	30.2	18.8	8.3	1.7	(*)
Burbank	11,036		(#)	99.6	96.4	79.9	58.6	42.3	30.0	18.6	9.4	3.7	1.1	.2	(*)	
Daggett	11,037				99.8	98.9	96.0	89.4	77.8	63.0	49.3	36.1	23.4	10.2	2.0	.1
Fresno	11,029			(#)	99.5	95.0	85.7	72.1	58.6	46.2	35.3	24.9	15.4	6.1	1.3	(*)
Oakland	11,016		(#)	99.0	85.9	48.5	26.3	10.1	4.1	1.6	.1					
Redding	11,040			(#)	99.1	96.5	91.3	81.2	66.2	49.7	35.8	22.5	11.2	3.6	.7	.1
San Diego	11,038				99.9	95.3	64.9	25.0	6.3	.9	.2					
Williams	11,036		(#)	99.6	95.9	87.0	75.8	64.3	53.8	43.4	33.4	23.4	14.1	5.8	1.6	.2
Colorado																
Denver	11,040	99.8	99.2	97.2	92.9	82.5	65.7	49.0	36.1	24.4	14.4	5.7	1.1	.1		
Pueblo	11,012	(#)	99.7	98.9	95.9	87.8	73.7	58.9	45.0	32.9	22.1	11.5	3.0	.1		
Connecticut																
Hartford	10,813	(#)	99.8	98.6	95.3	85.1	70.0	50.9	30.9	16.2	6.2	1.4	.2			
Florida																
Jacksonville	11,040						99.5	95.2	67.9	41.7	25.7	10.6	1.8	.1		
Miami	11,034						99.8	96.5	73.1	43.5	20.6	.8				
Titusville	11,025						99.8	94.5	64.2	38.5	20.1	2.5	.1			
Georgia																
Atlanta	11,028				(#)	99.5	97.4	84.4	55.1	35.4	19.8	7.2	1.2	(*)		
Idaho																
Boise	10,940	99.7	98.4	94.3	86.4	74.7	62.1	50.2	38.9	28.2	18.7	9.8	3.0	.6	(*)	
Burley	10,992	99.4	97.0	91.2	82.3	69.6	55.7	42.8	30.7	20.8	11.7	4.1	.7	(*)		
Idaho Falls	11,006	98.9	95.3	87.9	76.5	62.4	48.5	36.0	24.9	15.7	7.0	1.4	.1			
Illinois																
Chicago	11,036		99.9	98.8	96.0	89.7	78.1	59.1	38.8	22.4	11.5	4.6	1.1	.3	(*)	
Moline	11,038		99.9	98.8	96.5	90.8	80.6	64.2	44.8	28.8	16.0	6.7	2.3	.8	.2	
Indiana																
Indianapolis	11,006			99.8	97.8	93.2	83.2	64.7	42.7	25.4	11.1	3.3	1.2	.4	(*)	
Iowa																
Des Moines	11,038		99.9	99.4	97.4	92.4	82.1	65.6	46.2	28.7	15.9	7.2	2.5	.8	.1	(*)
Kansas																
Wichita	11,026		(#)	99.9	99.1	97.2	92.6	81.4	64.3	46.7	32.0	19.8	10.0	3.1	.8	.1
Kentucky																
Louisville	11,036			99.9	99.2	96.1	89.1	74.4	51.1	32.6	16.4	5.5	1.5	.3	(*)	
Louisiana																
New Orleans	11,036							99.5	87.0	50.0	25.4	7.4	.6	(*)		
Shreveport	11,040					(#)	99.5	96.1	77.7	52.6	34.5	19.4	6.2	.7	(*)	
Maryland																
Baltimore	11,025		(#)	(#)	99.8	97.9	91.0	74.9	50.8	27.8	13.3	3.5	.6	.1		
Massachusetts																
Boston	11,039			99.9	97.7	86.8	68.5	44.7	23.2	11.0	4.1	1.0	.1			
Michigan																
Detroit	11,039		(#)	99.1	95.9	88.4	75.2	55.0	33.9	17.8	6.7	1.9	.6	.2		
Minnesota																
St. Paul	11,038	(#)	99.5	98.4	95.5	87.7	74.0	56.1	37.8	22.1	10.7	3.6	1.1	.4	.1	(*)
Missouri																
Kansas City	11,015			99.9	99.4	97.4	92.4	82.5	66.4	48.9	31.8	18.9	9.5	3.2	.7	
St. Louis	11,039			(#)	99.4	96.9	91.2	78.2	58.6	39.4	23.1	10.8	4.1	1.4	.1	
Springfield	11,000			99.9	99.0	96.3	89.1	71.5	50.4	33.7	20.7	10.1	3.3	.7	(*)	
Montana																
Billings	11,040	99.8	98.7	94.6	87.2	75.4	59.6	44.5	31.1	20.0	11.4	5.1	1.5	.2		
Butte	11,025	95.1	87.6	75.3	61.3	47.9	36.3	25.6	16.8	8.3	2.6	.4	.1			
Nebraska																
North Platte	11,011	(#)	99.6	97.8	94.0	86.5	75.6	59.5	45.1	32.0	21.5	11.9	4.9	1.6	.2	
Omaha	11,031		(#)	99.6	98.0	94.5	86.6	73.4	55.8	38.1	23.6	12.8	5.4	1.7	.4	(*)
Nevada																
Elko	11,033	97.9	93.2	84.9	74.6	64.4	53.6	43.5	34.3	24.6	15.1	6.2	.7	(*)		
Reno	11,030	98.8	95.3	86.8	76.5	65.0	54.9	45.4	35.4	25.3	15.4	6.4	1.5	.1		
New Jersey																
Camden	11,013		(#)	99.9	99.5	95.7	85.3	67.8	43.9	25.5	12.2	3.6	.5	.1		
Newark	11,032		(#)	99.9	99.5	94.7	81.6	61.6	35.6	18.0	7.0	1.7	.3	.1		
New Mexico																
Albuquerque	11,037		(#)	99.6	98.5	94.2	81.0	62.8	47.4	33.0	20.3	7.9	1.2			
El Morro	11,032	98.3	95.3	89.4	78.3	61.8	49.2	37.3	24.2	10.3	1.9	(*)				
Rodeo	10,861			99.9	99.4	98.0	93.4	77.7	60.4	45.0	31.7	17.5	5.2	.3		
Tucumcari	11,033		(#)	99.9	99.2	96.2	86.5	69.8	53.0	39.3	27.2	15.4	4.8	.4	(*)	

See footnote at end of table.

TABLE 1.—*Percent of hours in summer (June-July-August) with temperature above indicated values. (First column shows total number of hourly readings, 1935–39 inclusive, used)*—Continued

		40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°	105°	110°
New York																
Albany	11,040		99.9	99.1	95.7	85.8	69.3	48.8	28.9	15.4	6.4	1.4	0.1	(*)		
Buffalo	11,039	(#)	99.8	98.4	92.6	81.7	66.0	45.1	26.2	11.6	3.4	.4				
Rochester	11,028		99.8	98.5	92.5	82.8	67.3	46.5	29.1	15.5	6.4	1.4	.3	0.1		
Syracuse	11,028		99.8	98.4	93.1	83.3	69.2	50.6	31.8	16.7	6.8	1.3	.3	.1		
North Carolina																
Charlotte	11,039				(#)	98.9	95.5	79.9	51.1	32.8	18.2	6.6	1.4	.1		
Greensboro	11,024			99.9	99.3	97.4	90.4	69.1	43.8	27.2	12.7	3.0	.3			
North Dakota																
Bismarck	10,084	99.6	98.1	94.8	88.4	77.7	64.2	49.6	36.3	24.4	14.7	7.4	3.4	1.3	0.4	0.1
Fargo	11,003	99.1	98.0	95.4	89.3	78.3	64.0	48.2	34.0	21.8	11.6	5.3	1.9	.7	.2	.1
Ohio																
Akron	11,038		99.8	99.0	95.0	87.1	74.1	52.4	32.0	17.4	6.4	1.3	.4	(*)		
Cincinnati	11,039		(#)	99.6	97.9	92.9	84.4	68.8	47.1	30.3	17.7	6.5	1.7	.5	.1	
Cleveland	11,040		99.8	98.8	95.5	87.9	75.9	55.8	35.7	20.5	9.3	2.6	.7	.3	(*)	
Columbus	11,039		99.9	99.3	96.9	90.8	79.8	60.0	38.1	22.1	10.1	2.2	.6	.2		
Toledo	11,039	(#)	99.8	98.9	95.7	88.0	74.3	54.4	34.8	19.9	9.0	2.9	.8	.2	(*)	
Oklahoma																
Ardmore	10,906				(#)	99.8	98.2	91.4	71.9	52.4	36.3	22.5	10.1	2.0	.3	
Oklahoma City	11,033				99.9	94.4	86.9	68.4	47.1	30.1	19.7	8.6	1.8	.4	(*)	
Tulsa	10,951			(#)	99.8	99.1	95.8	86.6	68.6	48.5	31.9	18.3	7.4	2.0	.3	
Waynoka	11,040			99.9	99.5	97.9	93.9	84.5	71.0	54.2	38.3	25.9	15.8	6.7	1.5	.2
Oregon																
Arlington	10,617		99.9	98.5	93.4	82.3	67.3	51.2	36.9	24.7	15.2	7.7	3.0	1.0	.2	(*)
Baker	11,016	98.5	94.2	86.1	73.8	59.8	46.6	34.3	24.0	14.8	7.5	2.5	.5	(*)		
Eugene	11,036	99.9	98.3	91.5	76.2	56.9	41.6	28.9	18.2	10.0	4.4	1.6	.6	(*)		
Medford	11,040		99.2	96.1	87.1	72.7	58.2	44.2	32.6	22.5	14.0	6.6	2.4	.5	.1	
Portland	11,037		(#)	99.1	91.3	67.7	45.1	28.4	16.7	8.6	3.5	1.5	.5	(*)		
Pennsylvania																
Curwensville	11,033	(#)	99.2	95.9	88.1	74.6	50.6	30.1	15.5	5.1	.8	.2	(*)			
Erie	10,993	(#)	99.7	98.6	94.2	84.2	68.3	45.5	23.7	8.9	2.5	.4	(*)			
Harrisburg	11,032		(#)	99.9	98.6	93.5	82.3	65.0	41.7	24.3	11.1	3.4	.6	.1		
Sunbury	11,034		(#)	99.5	96.6	89.2	75.4	54.5	34.1	19.8	7.6	1.6	.2	(*)		
Pittsburgh	10,506			99.9	97.8	91.2	78.4	54.2	33.0	16.9	6.0	1.1	.2	(*)		
South Carolina																
Charleston	11,030				(#)	99.6	97.7	88.8	58.1	34.2	16.0	3.3	.5			
Tennessee																
Chattanooga	11,033			(#)	99.6	98.2	94.0	79.2	53.5	36.4	21.8	8.5	1.8	.2		
Memphis	11,026				99.9	99.3	96.8	88.8	67.9	45.3	28.6	13.6	4.3	.5		
Nashville	10,979			(#)	99.6	98.3	94.2	82.2	58.2	37.8	22.1	8.9	2.2	.3		
Texas																
Abilene	11,033					99.8	98.4	90.8	71.6	51.2	35.0	19.8	5.7	.5		
Amarillo	11,037		(#)	99.7	99.0	95.9	85.8	68.5	51.8	37.3	24.6	12.6	3.4	.3	(*)	
Dallas	11,039					(#)	99.5	96.9	84.7	60.4	41.0	24.8	10.6	1.9	.2	(*)
El Paso	11,039					99.8	97.6	85.0	66.7	48.4	32.8	17.2	4.6	.4		
Houston	11,028						99.9	97.8	71.6	44.5	27.6	8.5	.9	.1		
San Antonio	11,005						99.9	98.0	80.4	54.1	36.6	21.1	7.6	.5	(*)	
Wink	11,005					99.8	98.3	87.8	67.7	50.1	36.1	23.3	9.9	2.0	.2	
Utah																
Milford	10,956	99.6	99.1	97.1	92.4	82.9	68.1	54.2	41.9	31.1	19.9	8.5	1.6	.1		
Salt Lake City	11,033	99.9	99.2	97.1	93.6	87.0	76.2	60.5	45.3	32.2	19.9	9.4	2.4	.2		
Virginia																
Richmond	11,006		(#)	99.9	99.4	96.7	88.6	71.5	45.6	27.8	14.7	4.4	.5	.1		
Washington																
Ellensburg	10,289	99.6	97.5	91.4	78.9	62.7	46.6	32.2	21.5	13.0	6.3	2.4	.6	.1		
Seattle	11,038		99.8	97.4	82.3	55.7	35.7	19.1	8.8	3.3	.9	.1				
Spokane	11,040	99.9	99.0	94.0	83.6	68.7	54.1	40.2	28.5	18.5	10.0	4.5	1.3	.2		
Wisconsin																
La Crosse	11,032	99.8	99.2	97.4	93.1	84.7	71.4	53.8	35.8	21.3	9.8	3.0	1.0	.3	(*)	
Madison	11,007	(#)	99.7	98.7	95.8	88.4	73.7	53.2	32.7	16.9	6.4	2.0	.7	.2	(*)	
Milwaukee	11,007		99.6	96.9	91.1	80.5	63.3	40.3	22.3	10.6	4.0	1.3	.4	.1		
Wyoming																
Cheyenne	11,022	99.0	96.9	92.4	82.3	66.6	51.2	37.9	27.4	16.5	7.5	.6	.1			
Rock Springs	11,034	98.2	94.7	87.2	76.5	62.5	49.0	37.0	26.0	14.8	5.7	.8	(*)			
District of Columbia																
Washington	10,987			(#)	99.9	98.3	92.5	77.2	53.1	31.8	16.5	5.2	.7	.1	(*)	

Between 99.95 and 100.00 percent.
* Between 0.00 and 0.05 percent.

Only seven places were colder than "normal," and only nine as much as 4° warmer, most of them in the central Great Plains. Thus, since the 1935–39 data, as summarized in table 1, may be considered as generally representative of a warm summer, there would appear to be somewhat less than one chance in six that the percentages will be substantially higher than those given for any of the 102 places.

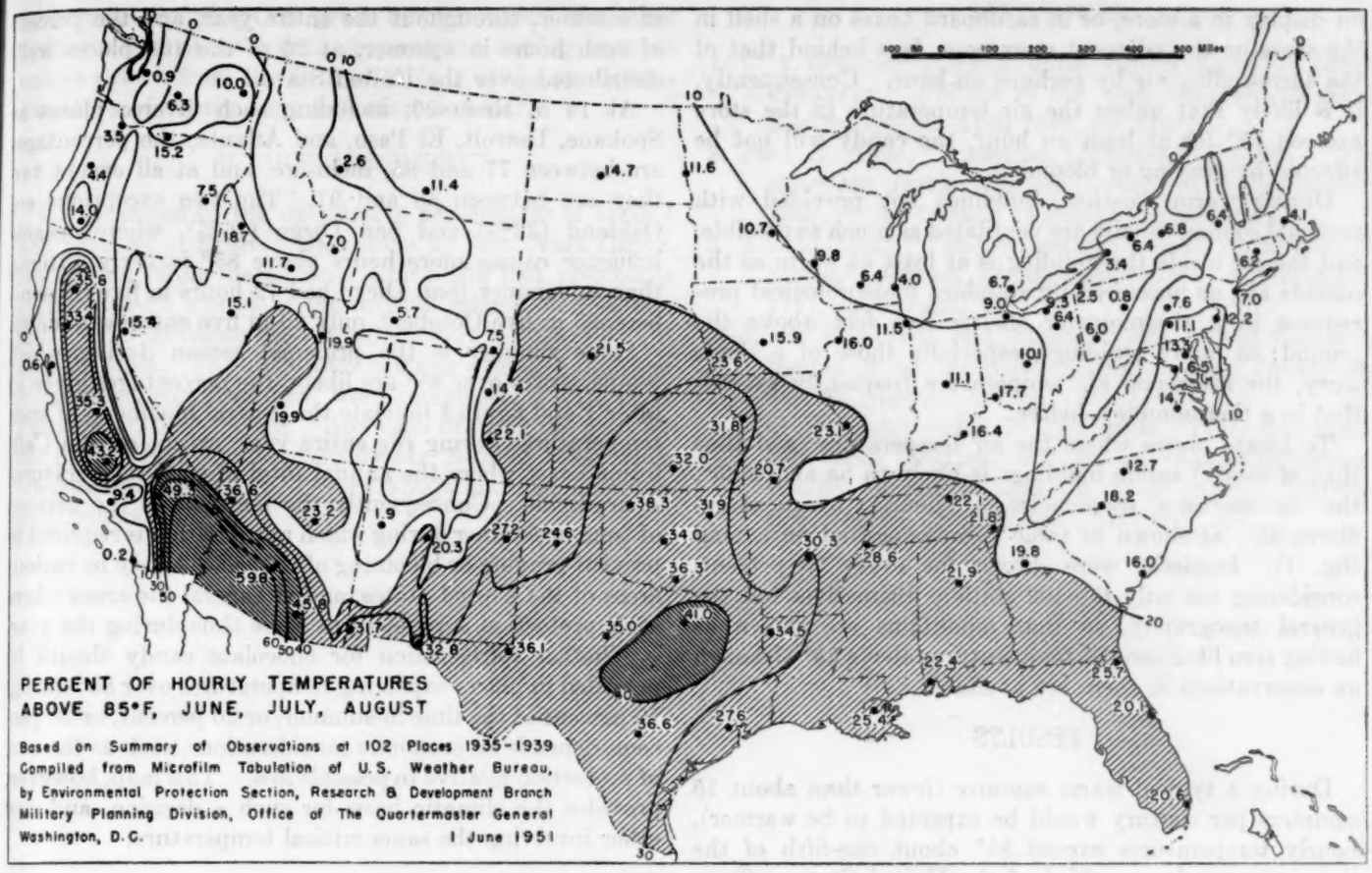
PERCENT OF HOURLY TEMPERATURES
ABOVE 85°F, JUNE, JULY, AUGUST
Based on Summary of Observations at 102 Places 1935-1939
Compiled from Microfilm Tabulation of U.S. Weather Bureau,
by Environmental Protection Section, Research & Development Branch
Military Planning Division, Office of The Quartermaster General
Washington, D.C. 1 June 1951

FIGURE 1.—Frequency of hourly temperatures above 85°F. in summer.

Only 15 of the 102 stations missed 40 or more hourly observations during the five summers, and eleven of these missed fewer than 223. The remaining four missed 413, 524, 751, and 956 observations, respectively. Most of the omissions were due to short cessations of operation, as when stations were moved, but may represent consistent skipping of one or more observations per day, usually at night, for one or more summers. Thus, for the few places with substantially less than the 11,040 observations of a perfect record, the percentages, because they are based on the actual number of observations and not the total possible, may indicate somewhat warmer conditions than would have been shown if all night-time hours were represented.

How well the hourly temperatures at each of the 102 stations represent the temperatures prevailing over the general area around the stations cannot be determined without detailed information on the locations of the stations and the conditions of thermometer exposure; such information has not been tabulated by the Weather Bureau. However, from the general conditions during those years at airways weather stations, at which nearly all of the observations were made, it appears that most of them (perhaps 80 percent) represent readings in regular thermometer shelters erected over sod or bare ground, on level terrain adjacent to airfields. Such readings should be representative of free air temperature, about five feet above the ground, over rather wide expanses, and thus generally applicable.

APPLICATION

This investigation, resulting in table 1, was the outgrowth of a simple problem in applied climatology: in what parts of the United States is refrigeration desirable to prevent deterioration of chocolate candy?

Detailed research at the Georgia Agricultural Experiment Station [4,5] has shown that "Temperatures from 85° to 95° cause graying or blooming of chocolates, even though exposure is only for a few hours." This undesirable change in the appearance of the candy "is a result of the melting of the layer of cocoa butter beneath the surface, causing it to penetrate the outer chocolate layer and become like 'cold grease' on the surface."

Since temperature above 85° F. appears, from this research, to be the critical factor causing the deterioration of chocolate candy, refrigerated cases to counteract such deterioration may be advisable in places where the candy temperature is likely to exceed this value on any substantial number of occasions. The temperature of candy

on display in a store, or in cardboard boxes on a shelf in the store or the adjacent storeroom, lags behind that of the surrounding air by perhaps an hour. Consequently, it is likely that unless the air temperature in the store exceeds 85° for at least an hour, the candy will not be affected by graying or blooming.

During warm weather, buildings not provided with artificial cooling usually are ventilated as much as possible, and the air inside the building is at least as warm as the outside air, as measured by standard meteorological procedures in a thermometer shelter five feet above the ground; in many buildings, especially those of a single story, the afternoon air temperature frequently exceeds that in a thermometer shelter.

To locate places where the air temperature (and thus that of candy) inside buildings is likely to be above 85°, the summertime frequencies of hourly temperatures above 85°, as shown in table 1, were plotted on a map (fig. 1). Isopleths were drawn for every 10 percent, considering not only the 102 stations themselves but the general topography, so that mountains are shown as having zero likelihood of temperatures above 85° although no observations in them are available.

RESULTS

During a typical warm summer (fewer than about 15 summers per century would be expected to be warmer), hourly temperatures exceed 85° about one-fifth of the time over nearly one-third of the United States. Two-fifths of all hourly readings are above this value in central Texas, central California, and the lowland desert area of California, Arizona, Nevada, and Utah.

On the other hand, less than one-tenth of all summer hours have temperatures above 85° along the Oregon-Washington coast, around the Great Lakes, and in the northeastern States; there is very little likelihood of such temperatures in the northern Rocky Mountains, the central Appalachians, and the mountains of northern New York and New England.

Temperatures above 85° occur in spring and autumn as well as in summer, but over most of the United States about four-fifths of the hours with such temperatures fall in the three summer months. Table 2 shows the number of hours during the five years with temperatures over 85° in summer, throughout the entire year, and the percent of such hours in summer, at 20 of the 100 places well-distributed over the United States.

At 14 of these 20, including such diverse places as Spokane, Detroit, El Paso, and Atlanta, the percentages are between 77 and 85, inclusive, and at all except two they are between 68 and 91. The two exceptions are Oakland (33%) and San Diego (16%), where oceanic influence causes more hours above 85° in early autumn than in summer (San Diego had 72 hours in five Septembers, 25 in five Octobers, only 20 in five entire summers).

Since summer is the principal season during which temperatures over 85° are likely, the percentages given in table 1 and figure 1 indicate the general likelihood of such temperatures during the entire year, except on the California coast where the annual total of such temperatures is negligible. Consequently the map shows the percent of time in summer during which refrigeration is required to prevent graying or blooming of chocolate candy in various areas of the United States, and in general the areas where such protection is required at some time during the year.

Whether refrigeration for chocolate candy should be provided in places expecting temperatures over 85° during 10 percent of the time in summer, or 20 percent, or 30 percent, depends on economic considerations, such as the cost of protection relative to possible loss. This map, however, provides the climatic basis for such a decision, and any other involving the same critical temperature.

OTHER USES

Other uses may be made of the map. For example, 85° is about the temperature (depending on humidity, ventilation, and radiation) at which human discomfort is first demonstrated by removal of coats, turning on of fans, and frequent trips to the water cooler. Until a more satisfactory index of such discomfort is developed, which would include humidity and air movement, and perhaps radiation, and climatic data are converted to it and tabulated, this map can serve as a rough index to the need for air conditioning or other means of alleviating the discomfort of hot weather.

Since the map shows the frequency of temperatures of 86° F. or over, which is exactly the same as 30° C. or over, it may be compared directly to similar maps prepared for

TABLE 2.—*Total hours during 5 years (1935–39) with temperatures over 85° F. in summer, throughout the year, and percent in summer*

	Summer	Year	%		Summer	Year	%
Salt Lake City, Utah	2,192	2404	91	Atlanta, Ga.	2,188	2,793	78
Syracuse, N. Y.	754	857	88	Waynoka, Okla.	4,227	5,395	78
Erie, Pa.	278	326	85	Louisville, Ky.	1,815	2,359	77
Spokane, Wash.	1,103	1,298	85	Medford, Oreg.	1,545	2,005	77
Madison, Wis.	704	848	83	Memphis, Tenn.	3,149	4,105	77
Omaha, Nebr.	2,602	3,154	83	Nashville, Tenn.	2,431	3,175	77
Detroit, Mich.	744	915	81	Fresno, Calif.	3,889	5,293	74
Kansas City, Mo.	3,504	4,359	80	Jacksonville, Fla.	2,838	4,180	68
El Paso, Tex.	3,624	4,593	79	Oakland, Calif.	63	191	33
Greensboro, N. C.	1,395	1,771	79	San Diego, Calif.	20	123	16

other countries using Centigrade temperatures. For other problems with other critical temperatures, analagous maps can be drawn from the data of table 1 of the percentage frequency of hourly temperatures in summer.

ACKNOWLEDGMENTS

Computation of the cumulative percentages of table 1 and plotting of figure 1 were done by Mrs. Vera Grove, statistician, from data cards which she had previously prepared from a copy of the original microfilmed tabulation. Annual values used in table 2 were furnished by Dr. Paul A. Siple. The 1935–1939 summer averages and their departures from "normal" were computed by Mr. O. S. Parmele, statistical clerk. Advice in drawing the percentage lines of figure 1 was given by Mr. Norman Sissenwine, meteorologist, and Drs. Peveril Meigs and Louis Peltier, geographers.

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THE WEATHER AND CIRCULATION OF FEBRUARY 1952[1]

A Month with a Pronounced Index Cycle

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One of the most interesting features of the circulation of February 1952 was the occurrence of a pronounced cycle in the zonal index during the month. The index cycle is defined as a gradual decline of the strength of the temperate-latitude westerlies from comparatively high to low values, followed by a similar rise. Namias [1] has shown that cycles lasting several weeks are prone to occur during February and March. This year the minimum point in the index cycle occurred near the middle of February, at least ten days earlier than all but one period studied by Namias, and more than twenty days earlier than the cycle in 1951 which was described by the author [2].

Figure 1 shows the time variation of the 5-day mean values of the temperate-latitude 700-mb. zonal index for the Western Hemisphere. The beginning of the index cycle may be defined as the high point in the graph, a value of 14.2 m/sec (more than 3 m/sec above normal) observed during the period centered on February 1. Incidentally this was the highest zonal index value observed during any 5-day mean period of the entire 1951–52 winter season. Note how the index values declined almost steadily until the very low value of 4.7 m/sec (more than 5 m/sec below normal) was reached on February 18. After a fairly slow rise during the next two weeks the index reached a value slightly above normal again on March 3.

Figure 2 depicts more completely the variation of the zonal westerlies during this index cycle. It is evident that the slowdown of the temperate-latitude westerlies was associated with a gradual shift of the major westerly belt southward from 43° N., where its peak speed was reached on February 1, to 33° N. by February 15. Thus, by February 18 a minimum speed of only 2 m/sec was found at latitude 48° N. After the minimum in the index cycle the average westerly wind belt was characterized by two distinct maxima, one axis shifting north of 40° N. while the other remained between latitudes 30° and 35° N. until it disappeared during the first week in March. Another noteworthy feature shown in this wind speed time section is the development of a secondary axis of maximum westerly winds between latitudes 60° and 70° N. in mid-February, which moved north of 70° N. by month's end. The behavior of the Western Hemisphere

[1] See Charts I-XV following p. 35, for analyzed climatological data for the month.

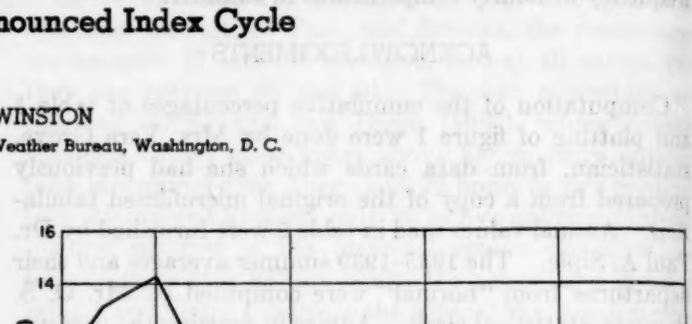

FIGURE 1.—Variation of temperate-latitude zonal index (average strength of zonal westerlies in m/sec between 35° N. and 55° N.) at 700 mb. over the Northern Hemisphere from 0° westward to 180° longitude. Solid line connects 5-day mean zonal index values (plotted at middle of 5-day period and computed twice weekly) for period from January 25 to March 12, 1952. Dashed line shows variation of monthly normal zonal index values for same period.

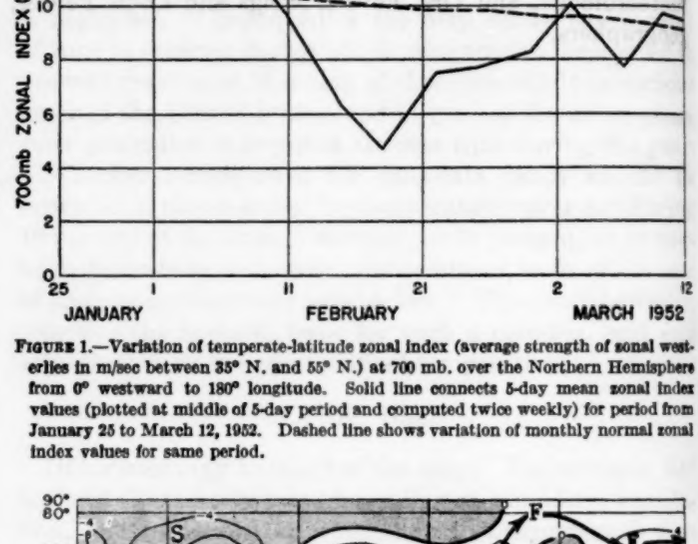

FIGURE 2.—Time-latitude section of 5-day mean zonal wind speed in Northern Hemisphere (averaged from 0° westward to 180° longitude) in m/sec at 700 mb. for period from January 25 to March 12, 1952. Isopleths are drawn at intervals of 4 m/sec. Areas with speeds greater than 8 m/sec are hatched; areas with negative speeds (easterlies) are stippled. Maximum speed centers are labeled "F", minima are labeled "S". Heavy arrowed lines mark latitudinal position of axes of maximum wind speed with time.

westerlies during this year's index cycle differed in one major respect from the cycle of February-March 1951 [2]. This year the major westerly belt shifted bodily southward, whereas last year the major westerlies shifted far to the north, and only then did a new westerly wind maximum develop at low latitudes. Whether this difference has any significance in terms of the subsequent behavior of the general circulation in each of the given years has not been determined. During both years, however, the westerly wind maximum was found at low latitudes near the time of the low point of the index cycle. This characteristic, originally emphasized by Rossby and Willett [3], was found by Namias [1] to apply during five out of six February-March index cycles from 1944 to 1949.

With such a large-scale, long-period variation in the westerlies occurring during the month of February it is not surprising that there were marked variations in the general circulation patterns during the month. Since the initial higher index phase of the cycle dominated much of the first half of the month while the lower index phase prevailed through most of the second half, the mean 700-mb. maps for the two halves of February provide an interesting contrast in circulation features (fig. 3). During approximately the first 15 days of the month the mean circulation was characterized by relatively fast westerly flow in an approximately sinusoidal wave pattern extending over almost three-fourths of the Northern Hemisphere from the east coast of Asia eastward to Europe (fig. 3A). Only over Asia was there a significant split in the major meandering westerly stream.

On the other hand, by the second half of the month, the circulation over about three-fourths of the Northern Hemisphere was dominated by anticyclonic conditions in northerly latitudes and cyclonic conditions at lower latitudes (fig. 3B). Warm closed Highs were located over northern Siberia and the northeastern Atlantic, and deep cold Lows were situated over southeastern Europe and the Gulf of St. Lawrence. Over North America a broad ridge covered central Canada, while cyclonic circulation was found to its south over the southern half of the United States. All of these features are rather typical examples of blocking action, of which low zonal index values are generally symptomatic. A split in the westerlies is strongly in evidence in figure 3B, with the higher latitude westerly belt extending from the Canadian Arctic eastward into the Siberian Arctic, while the stronger and more extensive belt in southerly latitudes extended almost unbroken from the western United States eastward through the Atlantic and the Mediterranean to the China coast. High index conditions with a single band of westerlies still prevailed over most of the Pacific in association with a deep Aleutian Low located near its normal position. Thus, as in the case of the March 1951 index cycle [2], the temperate westerlies over one sizable portion of the Northern Hemisphere were apparently undisturbed by widespread blocking action which had infected all other portions

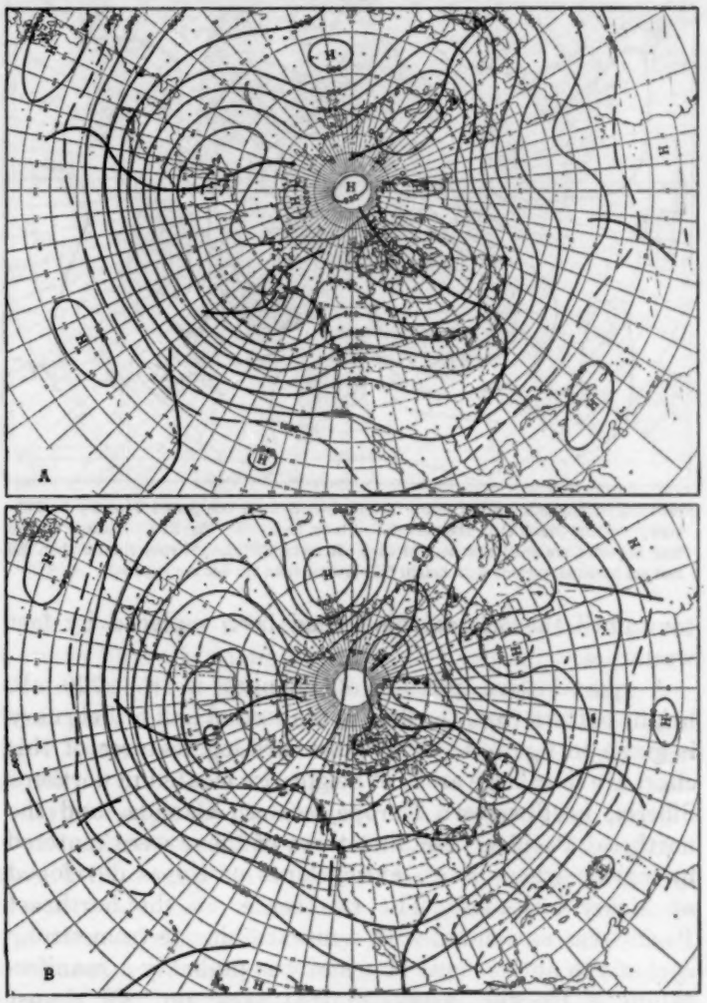

FIGURE 3.—Fifteen-day mean 700-mb. charts for (A) January 30–February 13, and (B) February 13–27, 1952. Contours at 200-foot intervals are shown by solid lines, selected intermediate contours at 100-foot intervals by dashed lines, and minimum latitude trough locations by heavy solid lines.

of the hemispheric circulation. It would be interesting to determine whether in all index cycles the extent of blocking action is limited in like fashion. A cursory inspection of charts of the low index stage of the index cycle (fig. 3 of [1]) reveals that in most cases which had sufficient hemispheric data a considerable area of the hemisphere was still dominated by fairly rapid westerly flow at middle latitudes. These findings may fit in with the idea of Rossby and Rex that the initiation of blocking is "more probable when a strong and relatively narrow westerly current system aloft prevails over the upstream area" [4]. Thus, if one considers that blocking usually spreads progressively upstream while the initial block persists [1, 5], it is obvious that there must be one longitudinal area of the hemisphere upstream from which strong westerlies do not exist. Presumably, the existing westerlies in this region would not decay as long as the westerlies are split and disorganized upstream. Therefore, a wave of blocking could not complete its circumpolar

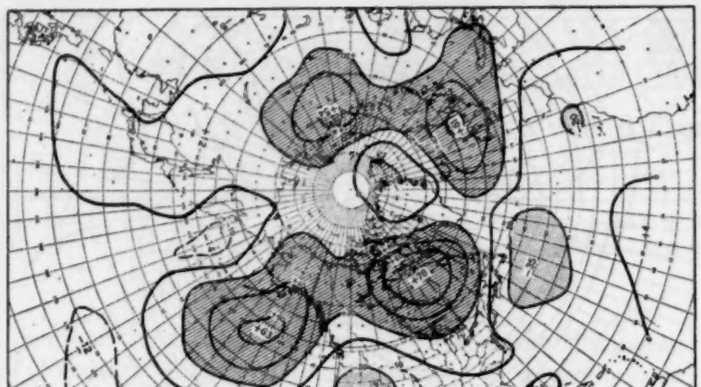

FIGURE 4.—Change in 15-day mean 700-mb. height from the period January 30-February 13, 1952 (fig. 3A) to the period February 13-27, 1952 (fig. 3B). Change centers and isopleths are labeled in tens of feet. Regions with height rises greater than 200 feet are hatched; regions with height falls greater than 200 feet are stippled.

tour until the original block had been replaced by fast westerlies.

A quantitative picture of changes in the 700-mb. height pattern from the first to the second half of February is given in figure 4. The most striking features of this chart are four large areas of height rise located in northern Siberia, northwestern Europe, eastern Canada, and the northeast Pacific. The first three of these were centered in regions where warm anticyclones or ridges developed at higher latitudes. The rise center in the northeast Pacific was associated with a marked change from strong cyclonic to anticyclonic flow and was probably a manifestation of blocking action in that area too. Of almost equal importance are the well-defined fall areas at lower latitudes in the western Atlantic and western United States. The relatively minor changes in eastern Asia and the western Pacific are also of interest in connection with the foregoing discussion of continued strong temperate-latitude westerly flow in that region.

Since the rise area centered over Hudson Bay was the most intense in the Northern Hemisphere, while fall centers to its southwest and southeast were likewise the most pronounced, it is apparent that the greatest regional decline in mid-latitude westerlies from the first to second halves of the month occurred over North America and the western Atlantic. This great change in circulation pattern had marked effects on the weather over the United States during the month. Representative of the changes in temperature from the first to the second halves of the month are the weekly temperature anomalies for the weeks ending February 12 and 26 (fig. 5). Figure 5A shows general warmth over virtually the entire United States with the greatest temperature anomaly in the northern Plains and along the eastern slopes of the Rockies. This is a rather typical pattern associated with fast westerly flow across the Continental Divide in western

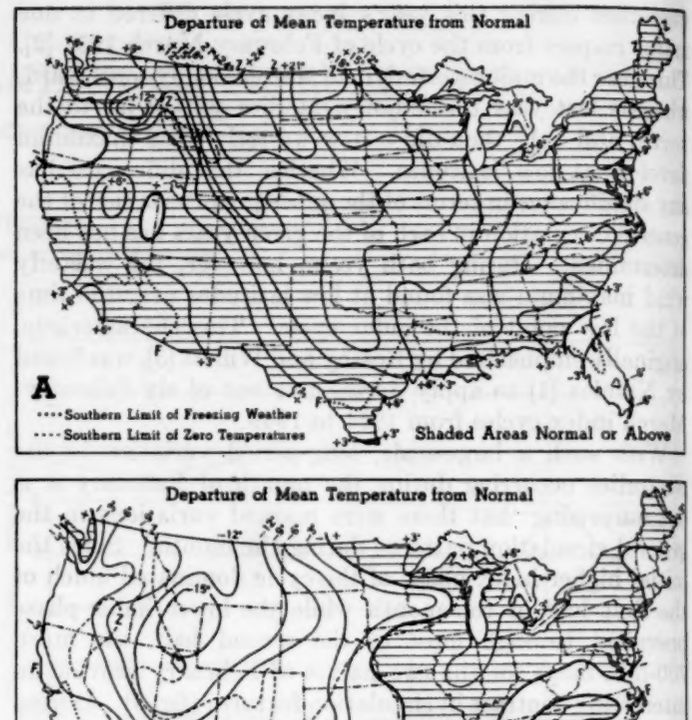
Departure of Mean Temperature from Normal
A
Southern Limit of Freezing Weather
Southern Limit of Zero Temperatures
Shaded Areas Normal or Above
Departure of Mean Temperature from Normal
B
Southern Limit of Freezing Weather
Southern Limit of Zero Temperatures
Shaded Areas Normal or Above

FIGURE 5.—Departure from normal of weekly mean surface temperatures in °F. for weeks ending (A) February 12 and (B) February 26, 1952. (From U. S. Weather Bureau, *Weekly Weather and Crop Bulletin* for above dates.)

Canada and northwestern United States. Two weeks later (fig. 5B), as the bottom of the index cycle was reached, temperatures were below normal in about two-thirds of the United States. Figure 6 portrays graphically the change to colder weather which took place between these two periods over practically the entire Nation. Note the tremendous fall in temperature anomaly in northern portions of the Rocky Mountain and Plains States. Miles City, Mont. experienced the maximum change, −39° F. Such large changes toward colder weather in the United States are quite characteristic of a drop from relatively high to extremely low zonal index values. The close connection between extreme values of zonal index, both high and low, and temperature regimes over the United States was pointed out twelve years ago in pioneering studies of extended forecasting [6].

Close inspection of Chart X reveals some of the effects of blocking and the index cycle on storm tracks during the month, especially in the eastern United States and western Atlantic. It can be seen that cyclones were fairly numerous in eastern Canada and the North Atlantic States in the first half of the month, when a deep trough

and strong westerlies were located over the region (fig. 3A). However, in the second half of the month there was almost a complete absence of cyclones in the same region while several storm centers moved through the Middle and South Atlantic coastal regions of the United States. This is readily explained by the appearance of the 700-mb. flow during the second half of the month (fig. 3B), when, as described earlier, anticyclonic conditions prevailed over eastern Canada and the westerlies were flat and strong at lower latitudes.

Three storms which passed through the Gulf of Mexico made a major contribution to the heavier-than-normal precipitation amounts observed along most of the Gulf Coast region and the lower Mississippi Valley (Chart III-B). Two of these storms proceeded northeastward off the East Coast. The one which formed a new center off Hatteras on the 16th deepened rapidly and led to intensive precipitation along the Middle and North Atlantic coast. In much of central and southern New England and eastern New York this produced the heaviest snowfall of the winter. The other storm, which left the Gulf of Mexico on the 26th, brought very heavy snow to extreme southeast New England.[2] Consequently New England reported abnormally heavy snowfall for February (Chart V-A). Nevertheless, precipitation on the whole in the Middle and North Atlantic States was subnormal (Chart III-B). These and most other regions of subnormal precipitation amounts (i. e., Great Lakes Region, Southwest, Kansas, and west Texas) were located under prevailing northwesterly flow at 700 mb. on the monthly mean chart (fig. 7).

Excessive precipitation in the Northern Plains and northern Rocky Mountain States (Chart III–B) is difficult to explain from the upper level monthly mean pattern (fig. 7). However, the area was located to the north of the paths of several cyclones during the month (Chart X). Much of this precipitation occurred with the slow-moving storm centered in Colorado on the 18th. This storm produced sizable amounts of snow in the entire region with the heaviest snowfall in parts of South Dakota and Minnesota. This cyclone was retarded in its eastward motion by an intense anticyclone over Hudson Bay (Chart IX). This High was associated with the previously mentioned large-scale blocking action operating over eastern Canada as the zonal index reached low values. The history of this High is rather remarkable, as may be determined by careful examination of Chart IX. Two notable features are worth mentioning. First, the high center meandered through eastern Canada for more than 15 days after it was first identified as a weak closed center late on the 9th northwest of Hudson Bay, finally crossing Newfoundland on the 25th. Second, rapid anticyclogenesis took place as the High lay over Hudson Bay between the 11th and 13th when the central pressure increased from 1016 to

[2] These storms are discussed in detail by Carr (see p. 28 of this issue of the *Monthly Weather Review*) and by Ludlum in the April 1952 issue of *Weatherwise*.

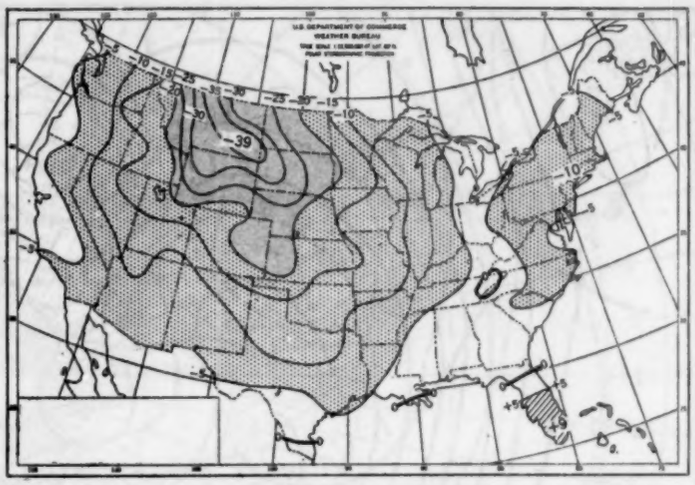

FIGURE 6.—Change in weekly mean surface temperature departure from normal from week ending February 12, 1952 (fig. 5A) to week ending February 26, 1952 (fig. 5B). Areas of negative changes between 5° and 20° F. are stippled while those in excess of 20° F. are more heavily stippled. Areas of positive change greater than 5° F. are hatched.

1040 mb. Since this one High prevailed over eastern Canada for such a long period while cyclones were generally absent, it is not surprising that monthly mean sea level pressure and 700-mb. height (Chart XI Inset and fig. 7) were considerably above normal through the entire region.

Even though the circulation and accompanying temperature regimes went through such large changes during the month in connection with the pronounced index cycle, the monthly mean circulation pattern and its anomaly still show a close relation to the monthly mean surface temperature anomalies over the United States (fig. 7 and Chart I–B). Although both the ridge over the western United States and the trough off the East Coast were slightly stronger than normal, the reversal of 700-mb. height anomaly pattern over Canada (i. e., above-normal heights in the trough, below-normal heights in the ridge) led to generally warm weather in most sections east of the Divide. Thus, the 700-mb. flow across most of Canada and the northern border of the United States was less northerly than normal, making strong outbreaks of continental polar air less frequent than normal for February, and at the same time allowing more opportunity for influxes of warmer air into the Canadian source region. The paucity of Canadian Highs crossing into the United States east of the Divide is quite evident in Chart IX. On the other hand, a large number of fast-moving cyclones traveled almost due eastward across southern Canada (Chart X) and probably led to frequent incursions of mild maritime Pacific polar air. Cool weather observed west of the Divide is very hard to explain on a monthly mean basis, but it may have been due to the presence of relatively weak anticyclonic flow aloft over a stronger than normal mean sea level Basin High (Chart XI). These conditions allow considerable radiational cooling especially when there is a substantial snow cover on the ground,

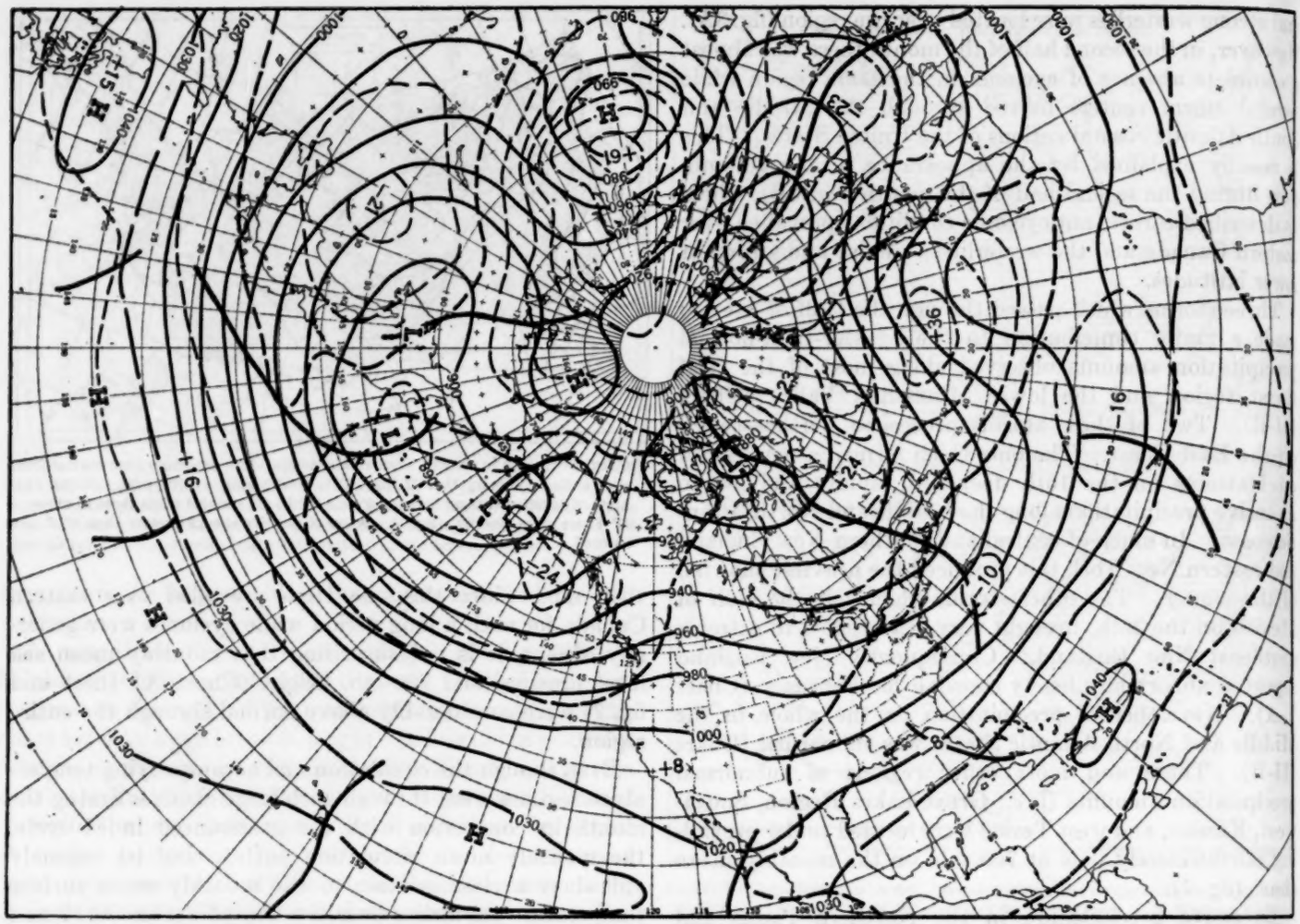

FIGURE 7.—Mean 700-mb chart for the 30-day period January 29–February 27, 1952. Contours at 200-foot intervals are shown by solid lines, intermediate contours by lines with long dashes, and 700-mb. height departures from normal at 100-foot intervals by lines with short dashes with the zero isopleth heavier. Anomaly centers and contours are labeled in tens of feet. Minimum latitude trough locations are shown by heavy solid lines.

as there was during this month. Even at month's end the Plateau region was still mostly snow-covered (Chart V-B).

In closing, it is interesting to note that this was the third successive February during which there was a marked difference in the circulation patterns observed over the Western Hemisphere between the first and second halves of the month [7, 8]. Further study is necessary to determine whether such pronounced breaks in large-scale circulation regimes are characteristic of most Februarys, and also to see how closely these breaks are related to the February-March index cycle.

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THE PRECIPITATION PATTERN ASSOCIATED WITH AN ATLANTIC COASTAL STORM

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INTRODUCTION

A surface wave which developed in the western Gulf of Mexico on February 25, 1952, moved northeastward across the Gulf to northeastern Florida. During the following 3 days it deepened and moved northeastward off the Atlantic Coast of the United States. This storm produced a wide area of rain over the Gulf States while the storm moved toward the East Coast but as it moved up the East Coast the rain changed to snow and, at the same time, the precipitation pattern over land narrowed considerably.

The narrowing of the coastal precipitation pattern combined with the threat of a moderate to heavy snowfall, presented a difficult problem to the forecasters in many of the major cities along the Atlantic coast, north of Cape Hatteras. This problem is discussed in this article.

Of all the Atlantic coastal regions affected, Cape Cod, Mass., received the heaviest snowfall and suffered the greatest storm damage. This situation is also discussed.

THE DEVELOPING STORM

In tracing the origin of this storm it is worthwhile to examine the upper air picture prior to the formation of the surface wave in the west Gulf region on the morning of the 25th.

At 1500 GMT, on that date, a small cut-off cold Low, or cold dome, at the 500-mb. level was centered above Amarillo, Tex., while, to the north, a stream of northwesterly winds entered the United States over eastern Montana. Over North Dakota the stream split. The major current swept forward in a cyclonic curve around a Low in the Great Lakes region. The minor branch swept southward and southwestward over the east slopes of the Rocky Mountains toward west Texas and New Mexico, pivoted around the cold dome and proceeded eastward and northeastward to rejoin the major stream over the mid-Atlantic coast. East of the small, cold Low aloft the isotherms and contour lines were in phase from Texas to the Atlantic coast, except for a small area at the center.

All in all, there was no indication of cold air surging southward into the Gulf but rather a sharp change to colder aloft as the upper cold dome passed eastward over each station, followed by a slow recovery to the previous temperature level. Typical of this change to colder was the 24-hour temperature drop at 500 mb. at 3 stations along the Gulf coast: Brownsville, Tex., had a 5° C. change, Burrwood, La., an 8° C. change and Lake Charles, La., reported a 24-hour change from −15.8° to −25.5° C. without any change in wind direction.

FIGURE 1.—Storm track and precipitation chart for February 25-29, 1952. Precipitation areas are shown for amounts of Trace or more; stippled areas indicate 1 inch or more in a 24-hour period ending the 26th (solid), the 27th (dotted) and the 28th (dashed). Storm tracks at the surface and at the 500-mb. level are shown by arrows. The blocked "X" indicates the 1230 GMT positions and central pressure of the surface Low while the solid blocks represent the 1500 GMT positions of the 500-mb. center.

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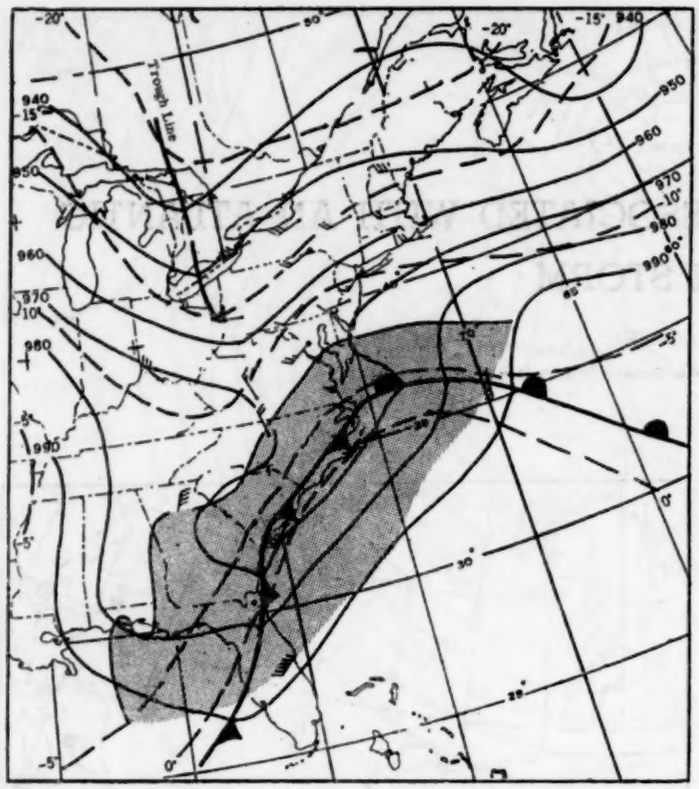


FIGURE 2.—700-mb. chart, 0300 GMT, February 27, 1952. Contours (solid lines) are at intervals of 100 geopotential feet. Isotherms (dashed lines) at intervals of 5° C. Fronts at the 700-mb. level. Barbs on wind shafts are for speeds in knots (full barb=10 knots). Shading indicates areas of active precipitation at the surface at 0330 GMT.

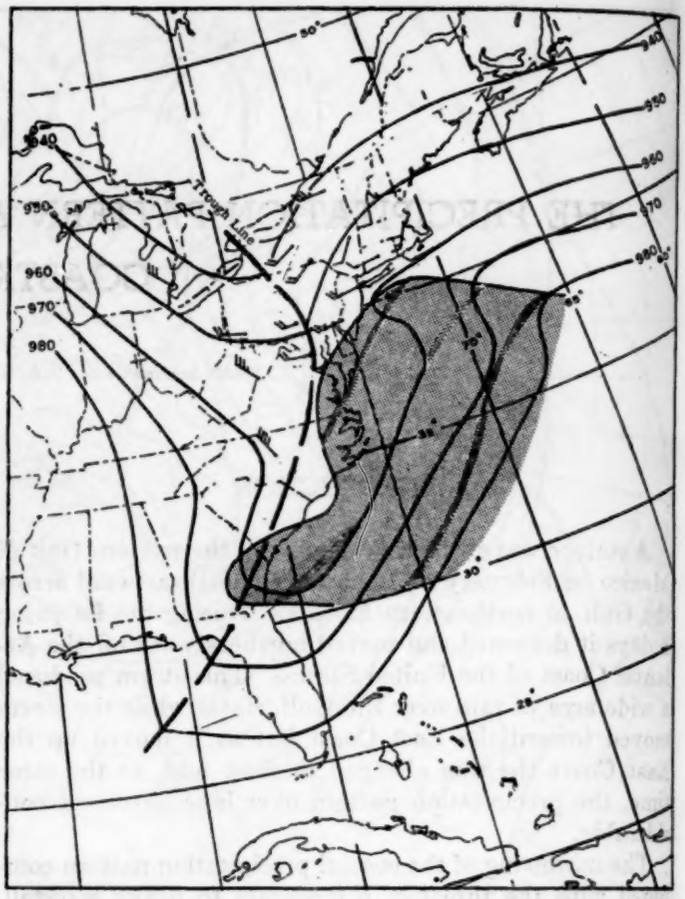


FIGURE 3.—700-mb. chart, 0900 GMT, February 27, 1952. Precipitation at 0930 GMT.

The 1500 GMT soundings on the 24th for Brownsville and Lake Charles showed that the lapse rate from the surface to the arbitrary level of 400 mb, was moist adiabatic for some layers and conditionally unstable for others. At the surface, at 1530 GMT on the 25th, Brownsville had a temperature of 68° F. and a dew point of 66° F., while Burrwood reported a temperature of 60° F. and a dew point of 58° F. Although the surface cold front had just arrived at Brownsville, the surface temperature indicated the presence of tropical air in the vicinity. The air over the northern portion of the Gulf was modified polar air. These conditions prevailed at the same time the cold air had begun to move in aloft. Considering only the air masses, the combination was a propitious arrangement of important factors contributing to the deepening of the surface storm; the necessary moisture supply, instability, and the advection of cold air aloft to intensify this condition.

As the upper center moved eastward from Amarillo, during the following 24 to 36 hours (fig. 1), the associated cold air invaded more southerly latitudes as a result of the sharpening of the upper trough. This intensification of the trough connecting the southern Low with the parent Low to the north resulted in an accentuation of the north-south orientation of the contour lines and formed a new flow pattern which aided in the destruction of the relatively warm air between the cold sources. Ultimately, as the cold air at both ends of the trough amalgamated (figs. 2, 5), there resulted a simpler flow pattern with tropical air to the east and polar air to the west of the trough lines. In other words, by the time the surface wave moved off of the south Atlantic coast it had a vertical structure which promoted the rapid development of the surface storm.

THE PRECIPITATION PROBLEM

The precipitation from the storm (fig. 1) was in the form of rain in the deep South but an increasing proportion of it became snow as the Low moved up the coast. From North Carolina northward, the precipitation was almost wholly snow on the west side of the storm track. This moving area of falling snow presented a problem in forecasting its influence on the various cities along the eastern coast. The problem was complicated by the fact that the occurrence, or nonoccurrence, of snow was a borderline condition for many major cities. There was the further threat that if snow did fall at a station it might amount to as much as 5 inches. Obviously, a small miscalculation on the position of the western limits

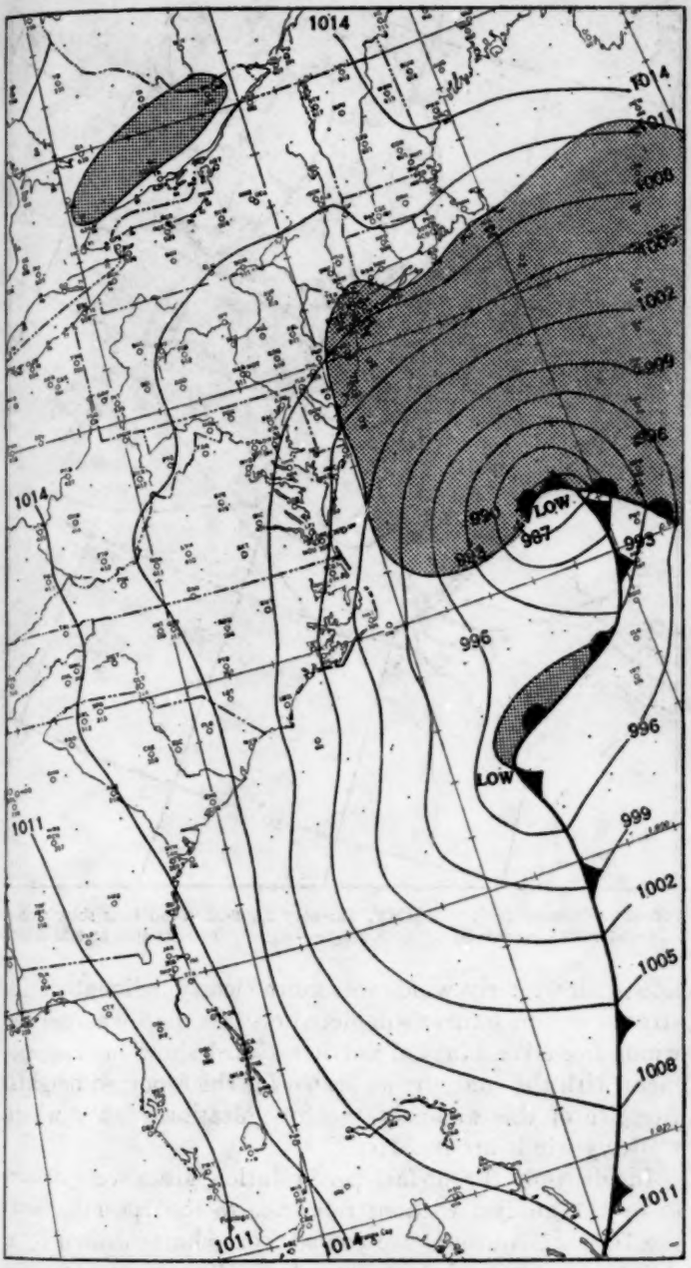


FIGURE 4.—Surface chart, 1500 GMT, February 27, 1952. Shading indicates areas of active precipitation.

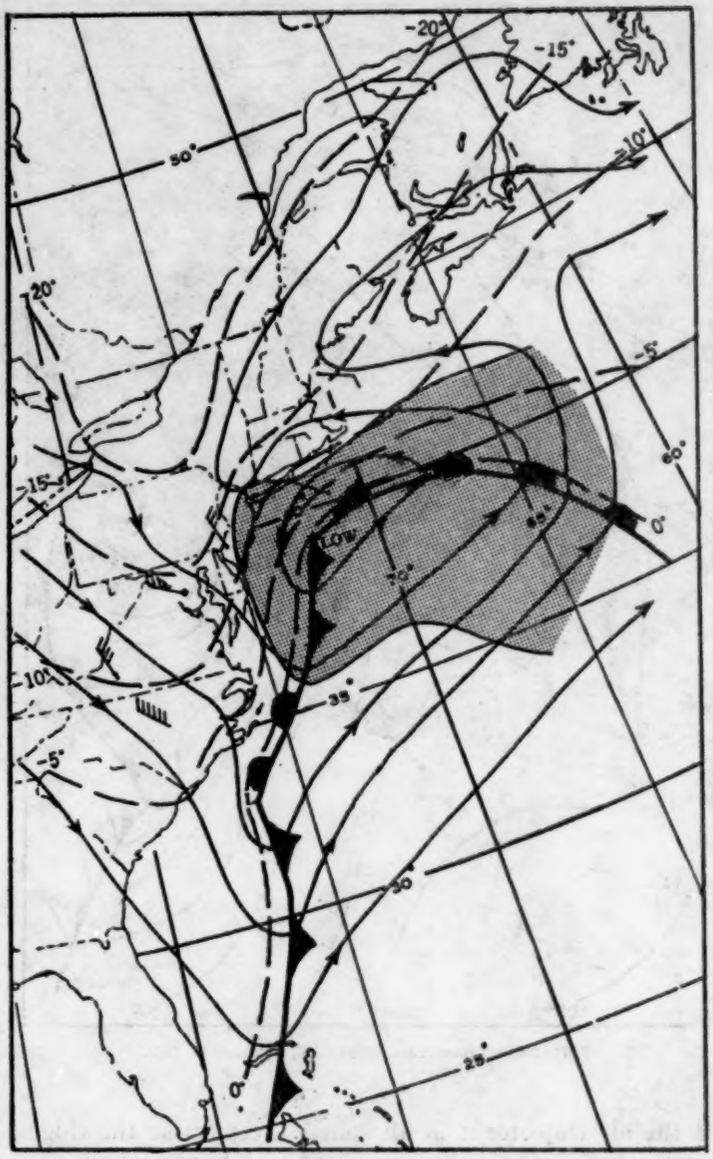


FIGURE 5.—700-mb. chart, 1500 GMT, February 27, 1952. Solid lines show airflow parallel to the contour lines. Precipitation at 1530 GMT.

could lead to a "no snow" forecast followed by a traffic-stalling depth of snow.

Just such a problem was involved in forecasting for Washington in the early morning hours of the 27th when the 0630 GMT map showed snow falling from the southern border of Virginia northward to a short distance south of the District of Columbia. Also, snow was falling east of Washington, at one time, as close as 20 miles away. The official forecast correctly called for snow east of the District in the morning and 2 to 4 inches along the Atlantic-coast of Delaware. Figure 1 demonstrates the borderline conditions the forecasters had to contend with along the mid-Atlantic and New England coasts. Note that from Virginia northward, the distance from the western Trace limit to the areas of 1 inch or more was quite short. In this storm the track of the 500-mb. Low seemed to be the western limit of 1 inch or more precipitation east of the Appalachian Mountains.

From Oklahoma eastward and up the coast this same track remained just east of the western edge of the precipitation area with the distance between the boundary and the track decreasing as the 500-mb. center and the surface center became more nearly aligned in the vertical. It appears that the region of the deepening 500-mb. Low was a center of maximum horizontal convergence in the lower layers of the storm. This activity could account for the relation between the heavy amounts and the upper track. Then, too, as Klein [1] pointed out, "the most important general parameter in determining precipitation

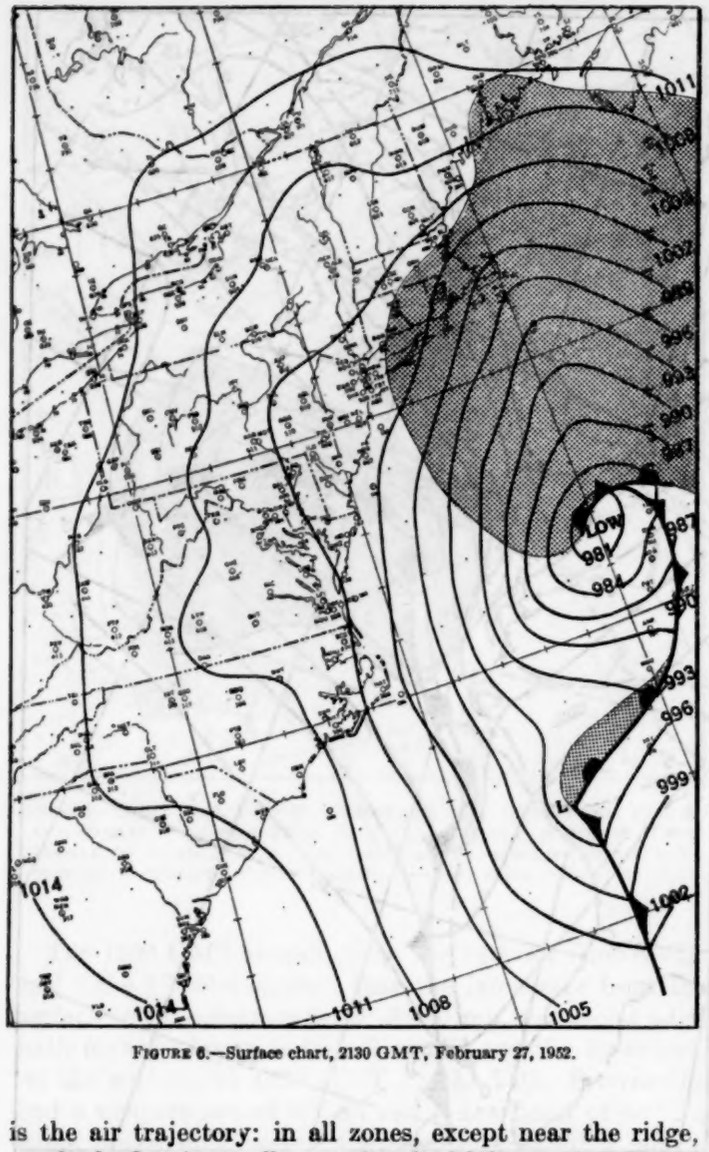


FIGURE 6.—Surface chart, 2130 GMT, February 27, 1952.

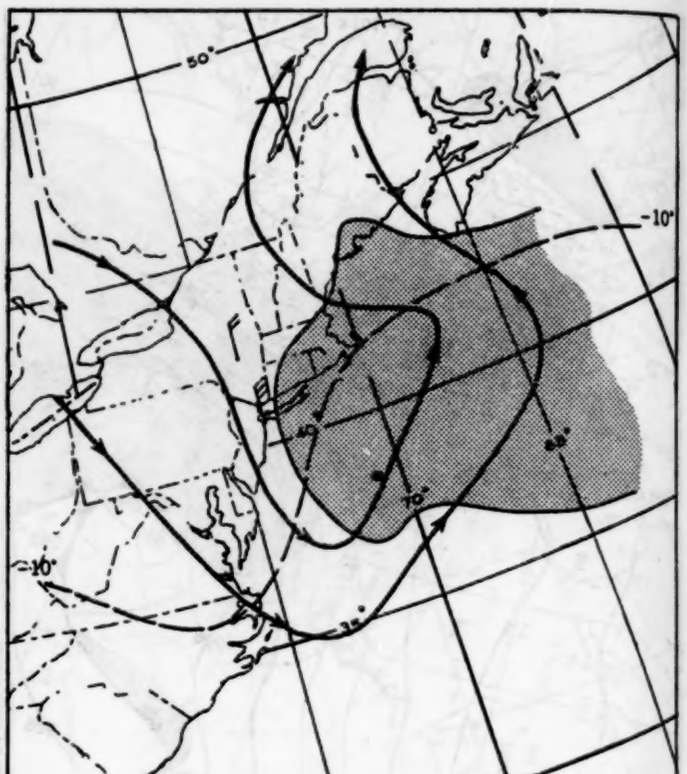


FIGURE 7.—700-mb. chart, 2100 GMT, February 27, 1952. Solid lines show airflow parallel to the contour lines. Isotherm for −10° C. Precipitation at 2130 GMT

is the air trajectory: in all zones, except near the ridge, southerly flow is usually associated with heavy (amounts), westerly with moderate (amounts) and northerly with light (amounts)". These observations are particularly applicable to the 700-mb. level but hold, in this storm, for the 500-mb. level as well.

When the forecast was being made for the Washington area there was evidence that the precipitation had already approached about as close to Washington as it would during this storm. This can be inferred by inspecting figures 2 and 3, which show a relationship between the precipitation and the air flow at 700 mb. Figure 2 by itself, however, is not sufficiently informative, but when interpreted in light of the knowledge that the trough over the Great Lakes was moving eastward while the wave in the southern end of the trough was moving northeastward, it foretold that precipitation was unlikely to come much closer to Washington. Thus the forecast for the Washington area could be justified.

Six hours later (fig. 3) the nonoccurrence of precipitation with westerly winds was more clearly delineated. A strange circumstance is depicted on this map wherein the winds from Washington northeastward show poor agreement with the contours as drawn for the reported heights. In spite of this anomaly the precipitation ceases where westerly winds are reported.

Incidentally the surface precipitation areas were drawn in by the analyst without reference to the 700-mb. flow; the 700-mb. contours are copied from charts drawn by a different analyst on duty that day. In other words, the combination of rain, snow, and air flow is a juxtaposition of 2 different maps independently drawn. Again in figures 5 and 7, drawn in the same independent manner, the surface precipitation ends in the region of the leading edge of the westerly flow.

THE STORM AT CAPE COD

Figures 4, 5, 6, and 7 show some details at the surface and the 700-mb. level as the deepening storm approached Cape Cod. By 1500 GMT on the 27th (fig. 4), the advancing line of snow had already reached Nantucket. A knowledge of the path so far taken by the center and the projected path indicated that the southern and eastern shore of the New England States would receive precipita-

tion. It could be presumed that the duration and intensity of the fall might be greater than was reported along the mid-Atlantic coast. The first observation was so for a number of reasons, chief among which was the direction of movement of the storm as it was related to the land mass of the northeastern States (the land extends farther eastward with increasing latitude). The second was also true because the storm had been deepening and the continuation of this trend could be expected to bring more moisture into the storm.

A comparison of figures 2 and 5 shows changes at the 700-mb. level which supported the preliminary concepts gained from an inspection of the surface maps. The most important change was the increasing cyclonic flow representing an increasing moisture supply and greater horizontal convergence to aid in lifting the moisture. As the storm moved northeastward the westerly winds at 700 mb. (fig. 2) over New England shifted to easterly (fig. 5) and finally southerly and southeasterly (fig. 7). This changing and intensifying air flow caused heavy snowfall at Cape Cod and a rapid spread of the precipitation to the north and northeast along the coasts of New England and Nova Scotia. Anticipation of such changes in the flow pattern seems to be prerequisite to correctly forecasting the precipitation pattern in well developed storms.

There were certain circumstances, in this case, which contributed to the production of snow at Cape Cod. Usually, coastal storms move north or northeast along, or off, the coast of the United States bringing snow to the adjacent land areas and, usually, rain to the Cape Cod-Nantucket region. This extreme easterly bit of land is usually in the warm sector (or sufficiently close to it) where the air is above freezing because of Gulf Stream modification. At other times, the Cape is in the region of above-freezing modified polar air. On still different occasions, the tip of the Cape is just on the western fringe of the snow area associated with a Low (far out at sea) moving northeastward. This situation usually brings light snowfall to the vicinity of the Cape.

This storm differed from the last described situation in a number of ways; first, the Low moved on a course with increasing northerly component with time; secondly, it deepened rapidly while moving close to the Cape and, at the same time, decreased its rate of progression. Along with a good supply of tropical air to the east of the storm track the situation was influenced by the steep slope of quite cold air to the west of the center. The strong southerly flow from the surface to above the 500-mb. level and the steep mass of cold air just west of the trough, produced two results: strong, increasing horizontal convergence in the warm air plus extensive and rapid lifting by the cold air over and above that related to the cold front. This accentuated lifting process combined with the strong infeed of moist tropical air provided just about optimum conditions for the production of precipitation, as the data from Nantucket certainly seem to prove.

The reports from Portland, Maine, Boston and Nantucket, Mass., are illustrative of the sharp gradient of snowfall previously mentioned. Portland received a total of 1.5 inches during the storm while Boston measured 5.2 inches but Nantucket received 14.9 inches on the 27th, 5.2 inches on the 28th, and an additional 1.3 inches on the 29th when a minor disturbance passed to the south of the Cape. The official storm total was 20.1 inches.

Nantucket had a snow cover of 3 inches on the evening of the 26th, 13 inches on the 27th, 20 inches on the 28th, and 17 inches on the 29th. Along with the previous snowfalls of 4.9 inches on the 18th and 10.1 inches on the 21st, the ground was covered with snow from the 18th to the end of the month. The comment at the end of the Local Climatological Data (Feb. 1952) for Nantucket stated, "Total snowfall for the month was 36.4 inches, which was the largest ever recorded for the month of February. The 20.1-inch fall on the 27-28th was the greatest ever recorded in any 24-hour period. On the 28th, the depth on the ground reached 23 inches, also an all-time record for any month."

Strong winds accompanied the snow at Nantucket on the 27th when the fastest mile was 61 m. p. h. from the northwest with an average for the day of 26.8 m. p. h. On the 28th, the fastest mile was 50 m. p. h. from the northeast with an average for the day of 23.1 m. p. h. This unhappy combination of a heavy fall of dry snow and gales brought considerable damage and hardship to the residents of the area.

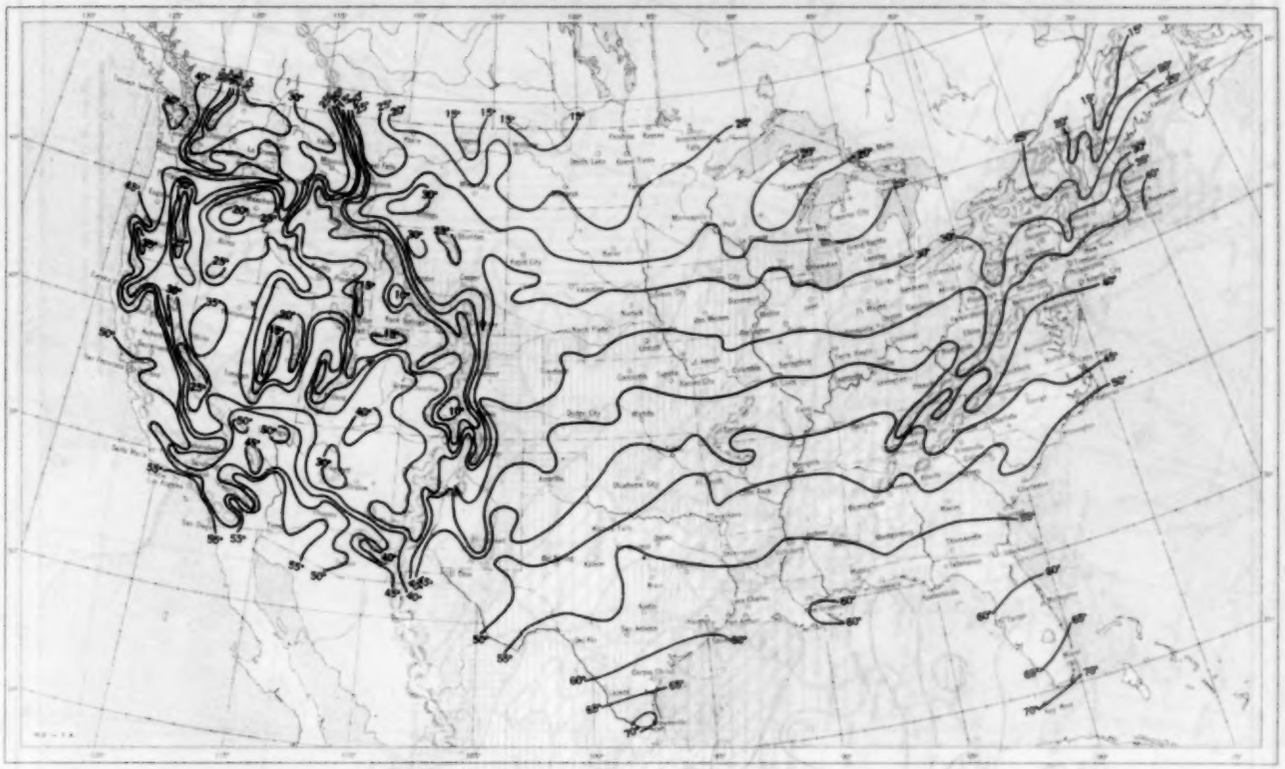
According to the local papers the resulting drifts, ranging from 10 to 15 feet, marooned an estimated 3,000 automobiles between the Cape Cod Canal and Provincetown, R. I., during the time the storm was raging near the Cape. Innumerable homes were without light and heat as power lines went down. Power company officials estimated 80 percent of the Cape's electric power was cut off at one time (about as great as the power failure during the 1944 hurricane). Storm damage was estimated to be near $500,000 and the death toll as of the 29th stood at 13.

REFERENCE

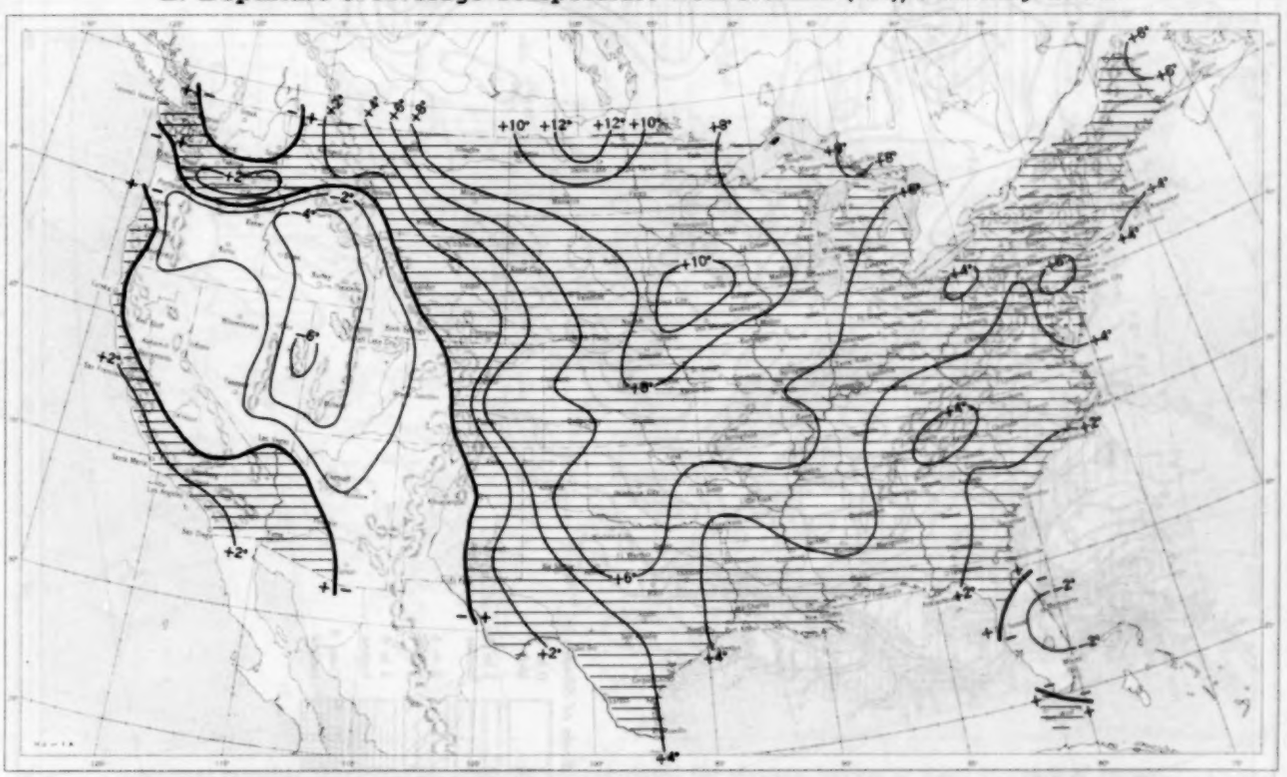
W. H. Klein, "An Objective Method of Forecasting Five-Day Precipitation for the Tennessee Valley," *Research Paper No. 29*, U. S. Weather Bureau, Washington, D. C., April 1949.

U. S. GOVERNMENT PRINTING OFFICE: 1952

Chart I. A. Average Temperature (°F.) at Surface, February 1952.



B. Departure of Average Temperature from Normal (°F.), February 1952.



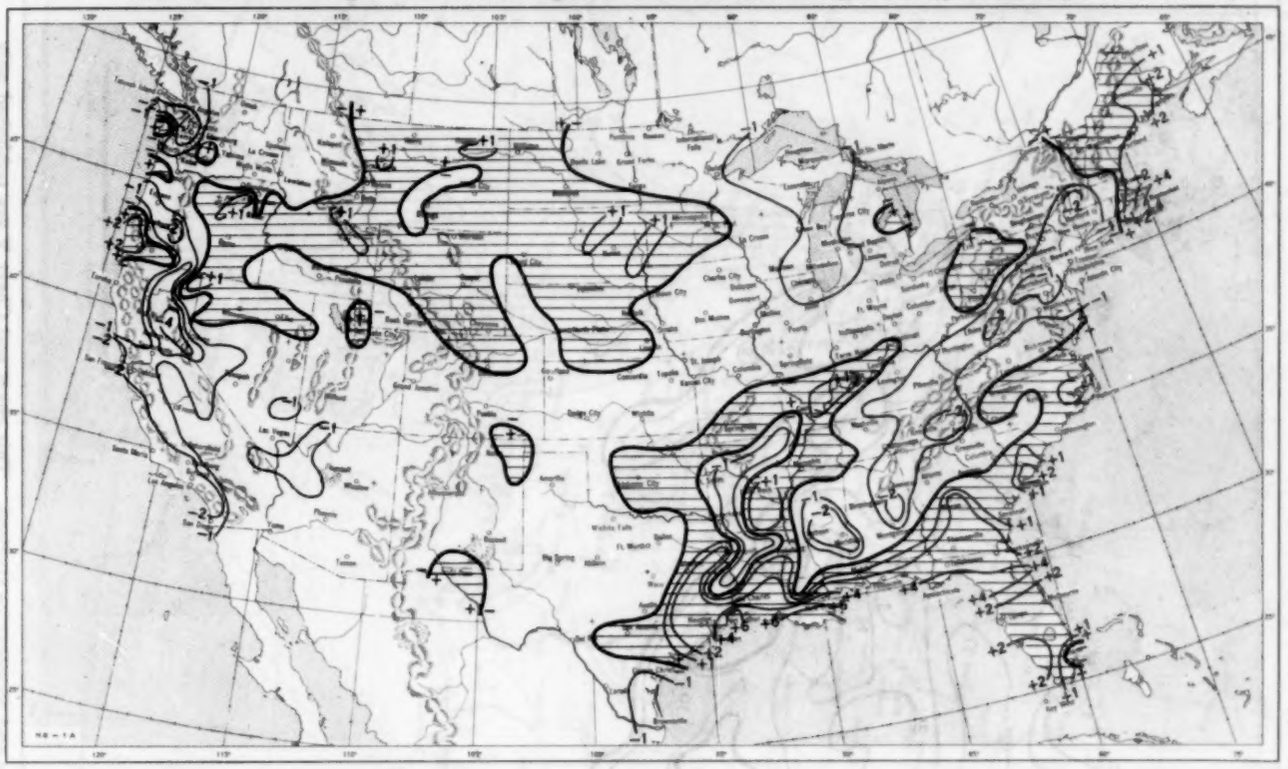
A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

Chart II. Total Precipitation (Inches), February 1952.

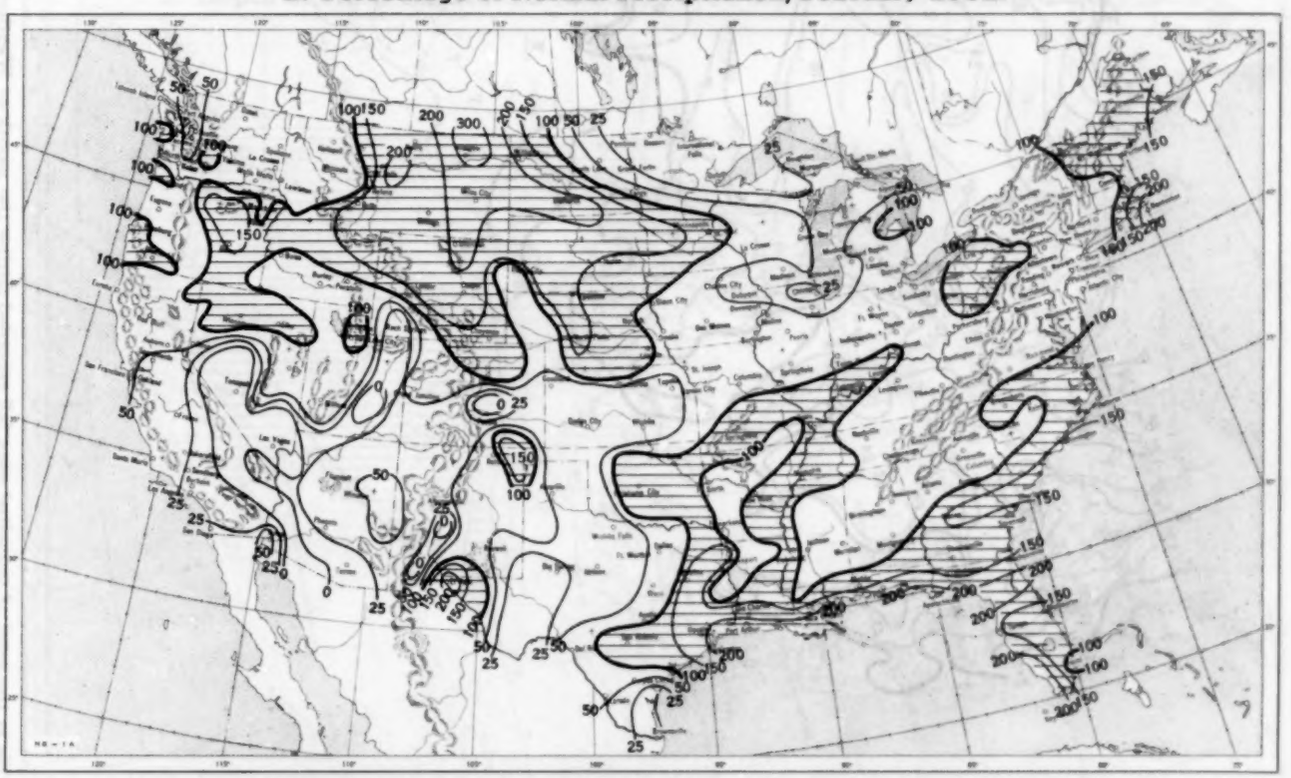
Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), February 1952.

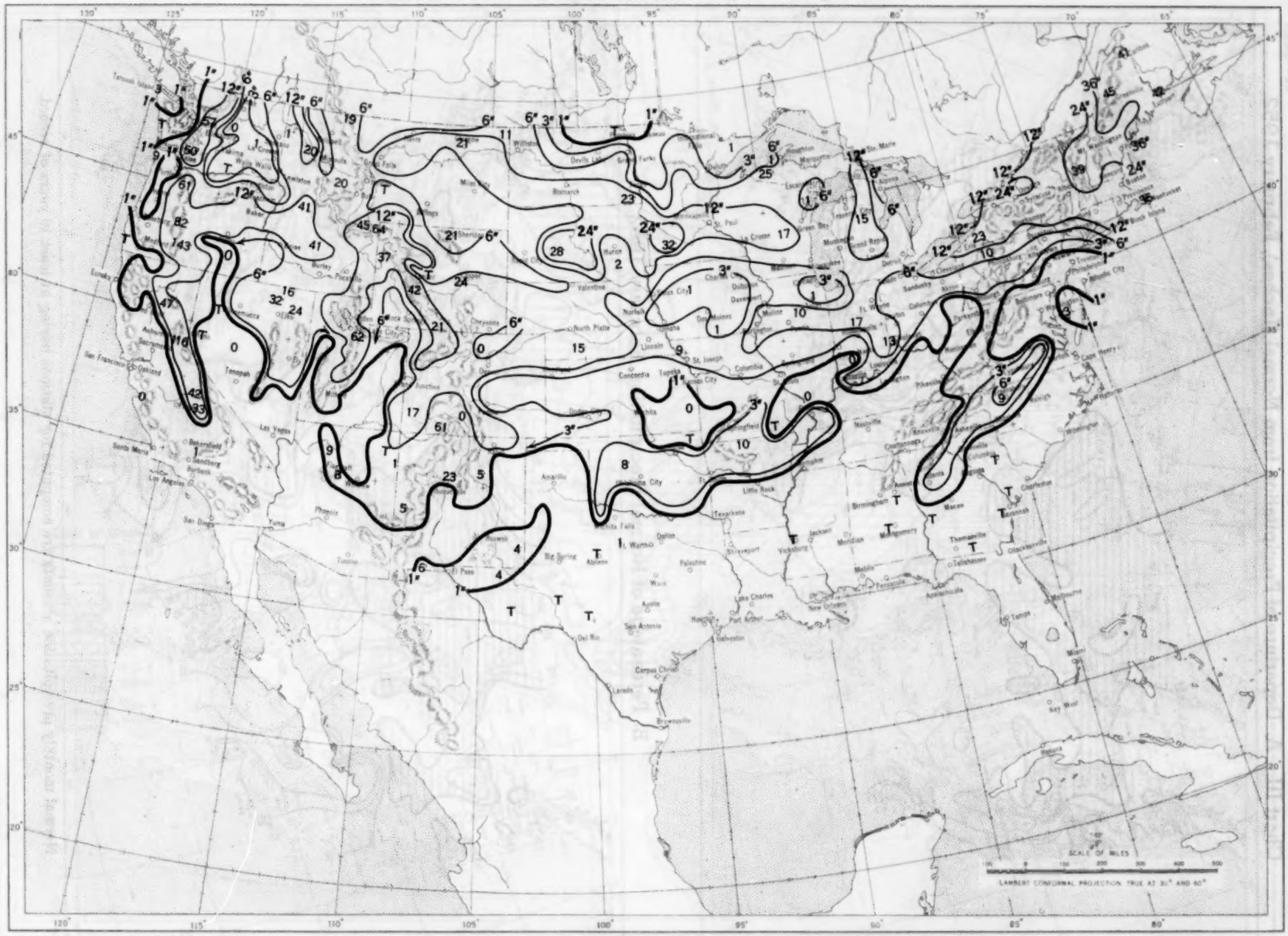


B. Percentage of Normal Precipitation, February 1952.



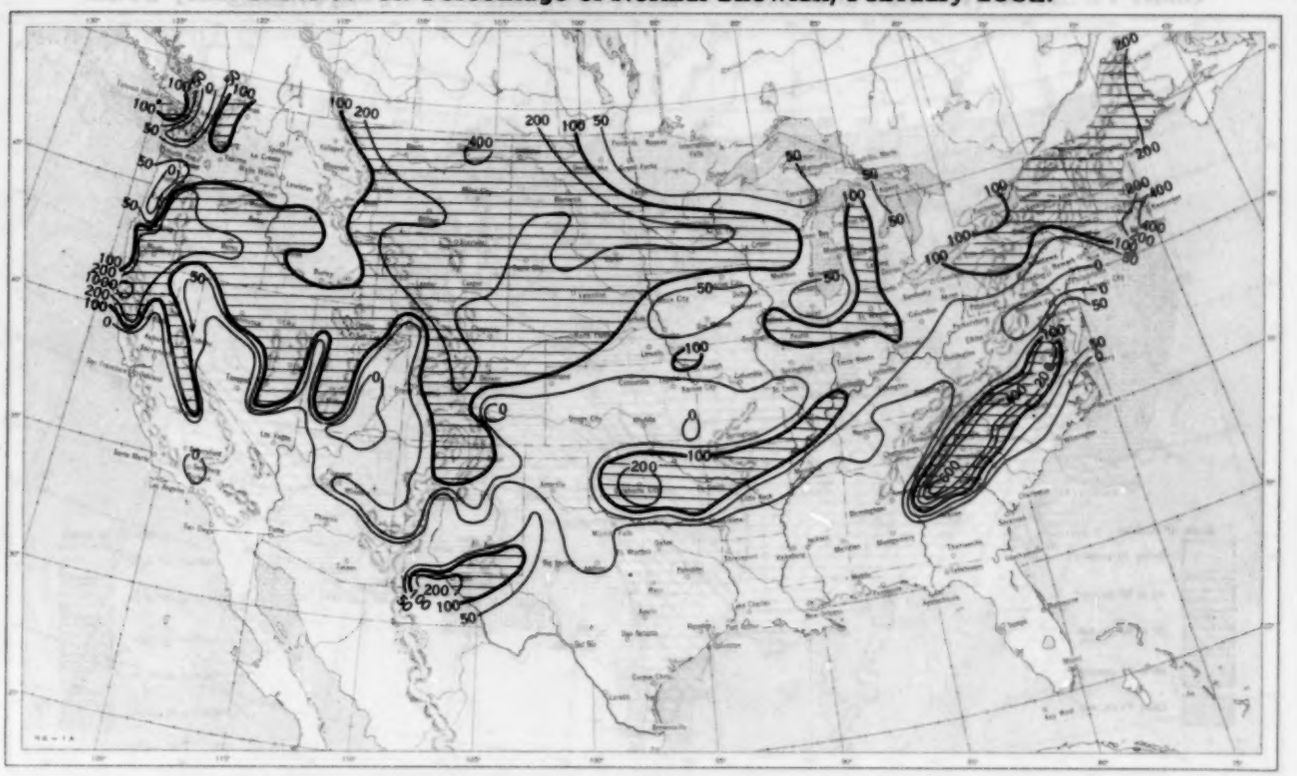
Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart IV. Total Snowfall (Inches), February 1952.

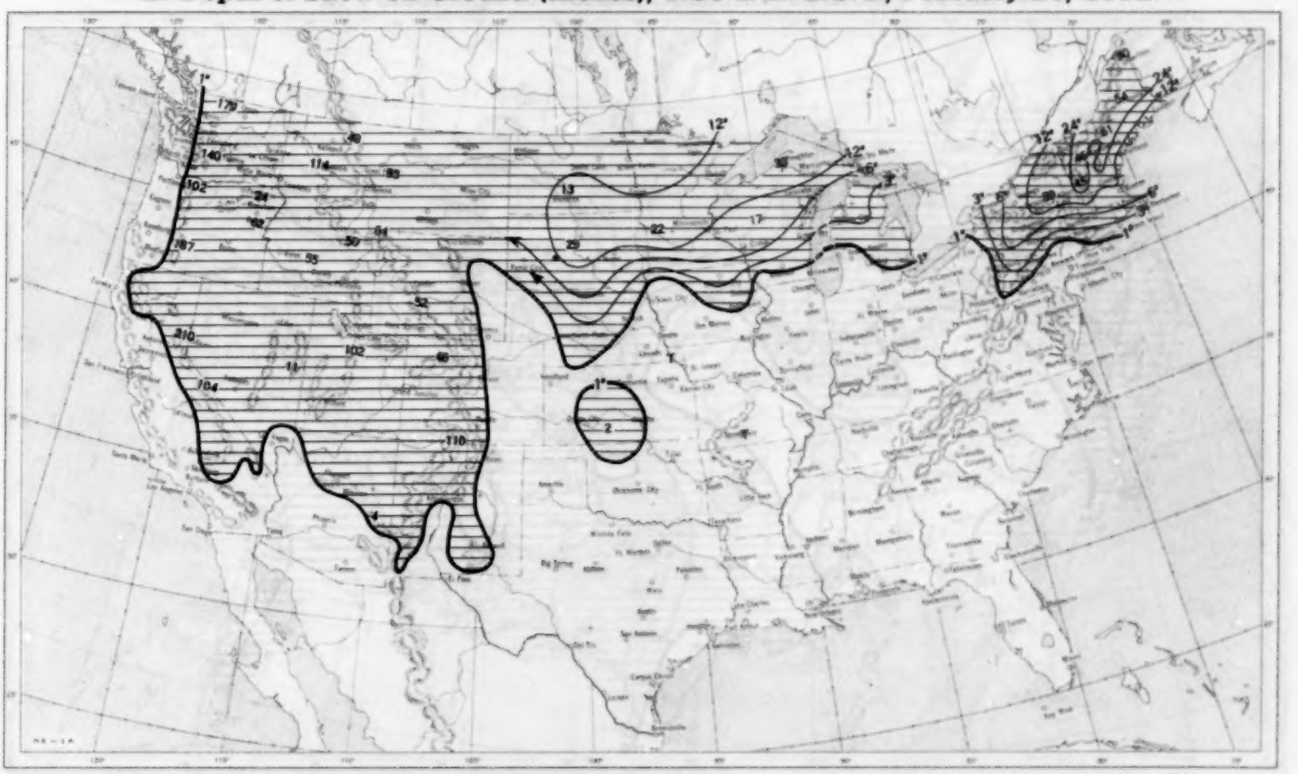


This is the total of unmelted snowfall recorded during the month at Weather Bureau and cooperative stations. This chart and Chart V are published only for the months of November through April although of course there is some snow at higher elevations, particularly in the far West, earlier and later in the year.

Chart V. A. Percentage of Normal Snowfall, February 1952.

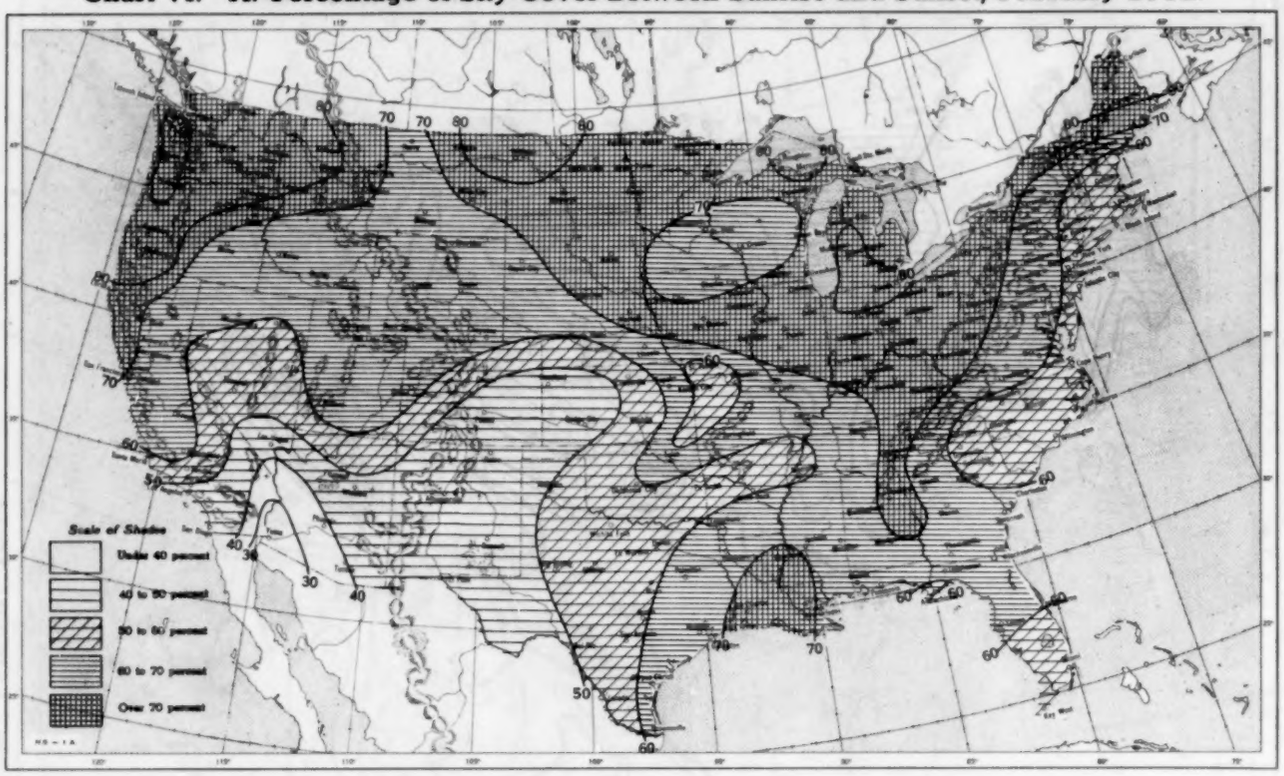


B. Depth of Snow on Ground (Inches), 7:30 a. m. E.S.T., February 26, 1952.

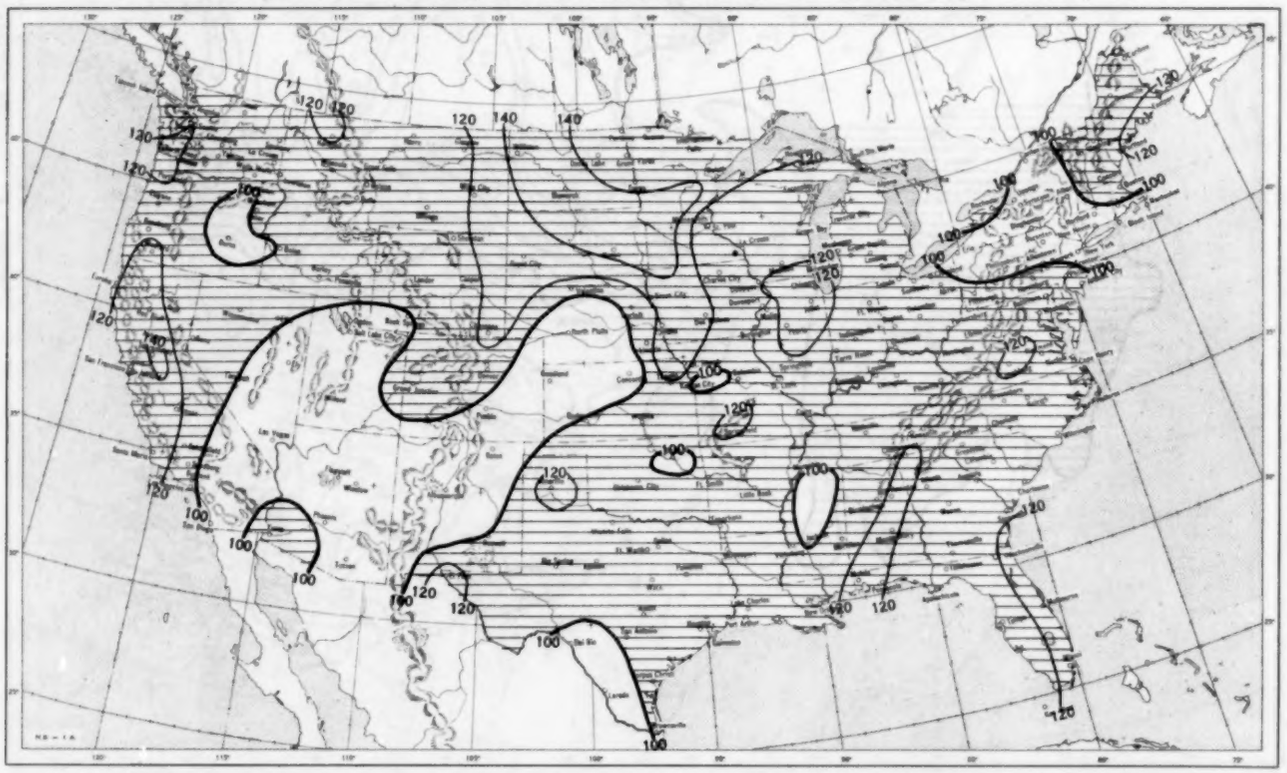


A. Amount of normal monthly snowfall is computed for Weather Bureau stations having at least 10 years of record.
B. Shows depth currently on ground at 7:30 a. m. E.S.T., of the Tuesday nearest the end of the month. It is based on reports from Weather Bureau and cooperative stations. Dashed line shows greatest southern extent of snowcover during month.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, February 1952.

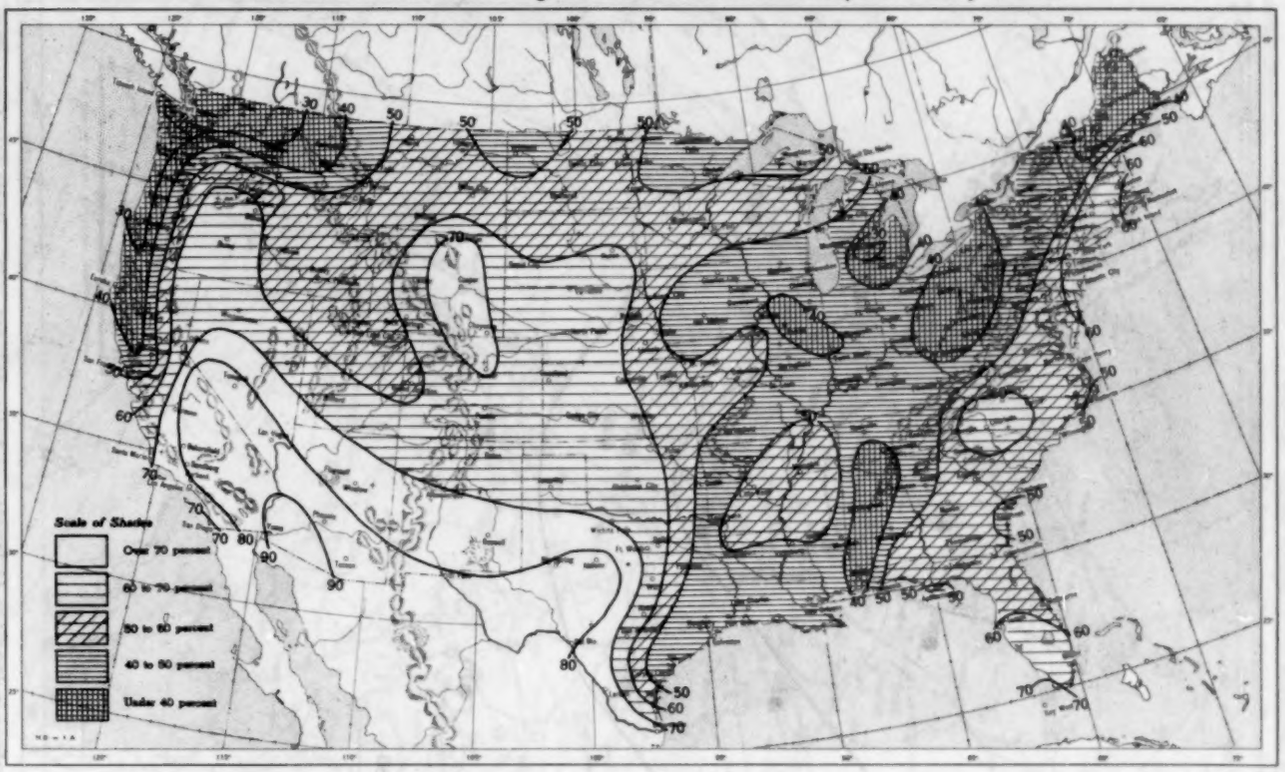


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, February 1952.

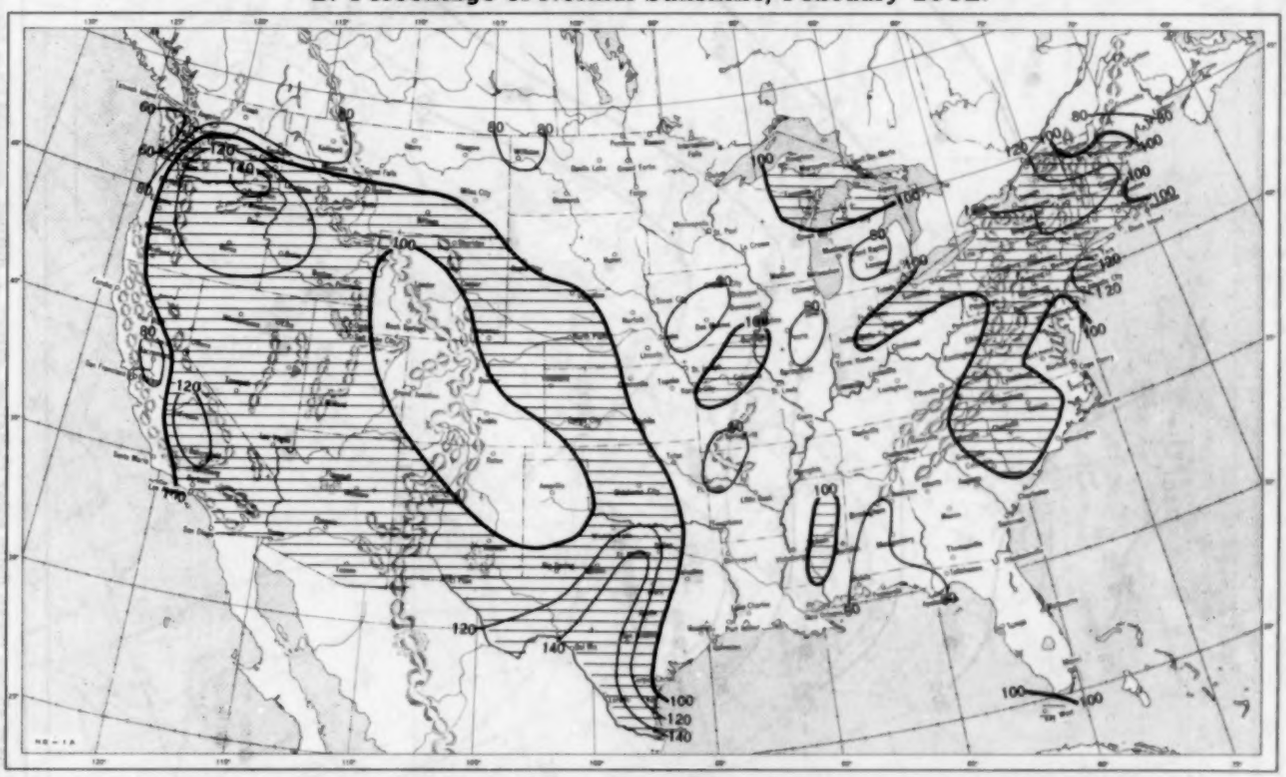


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, February 1952.



B. Percentage of Normal Sunshine, February 1952.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, February 1952. Inset: Percentage of Normal Average Daily Solar Radiation, February 1952.

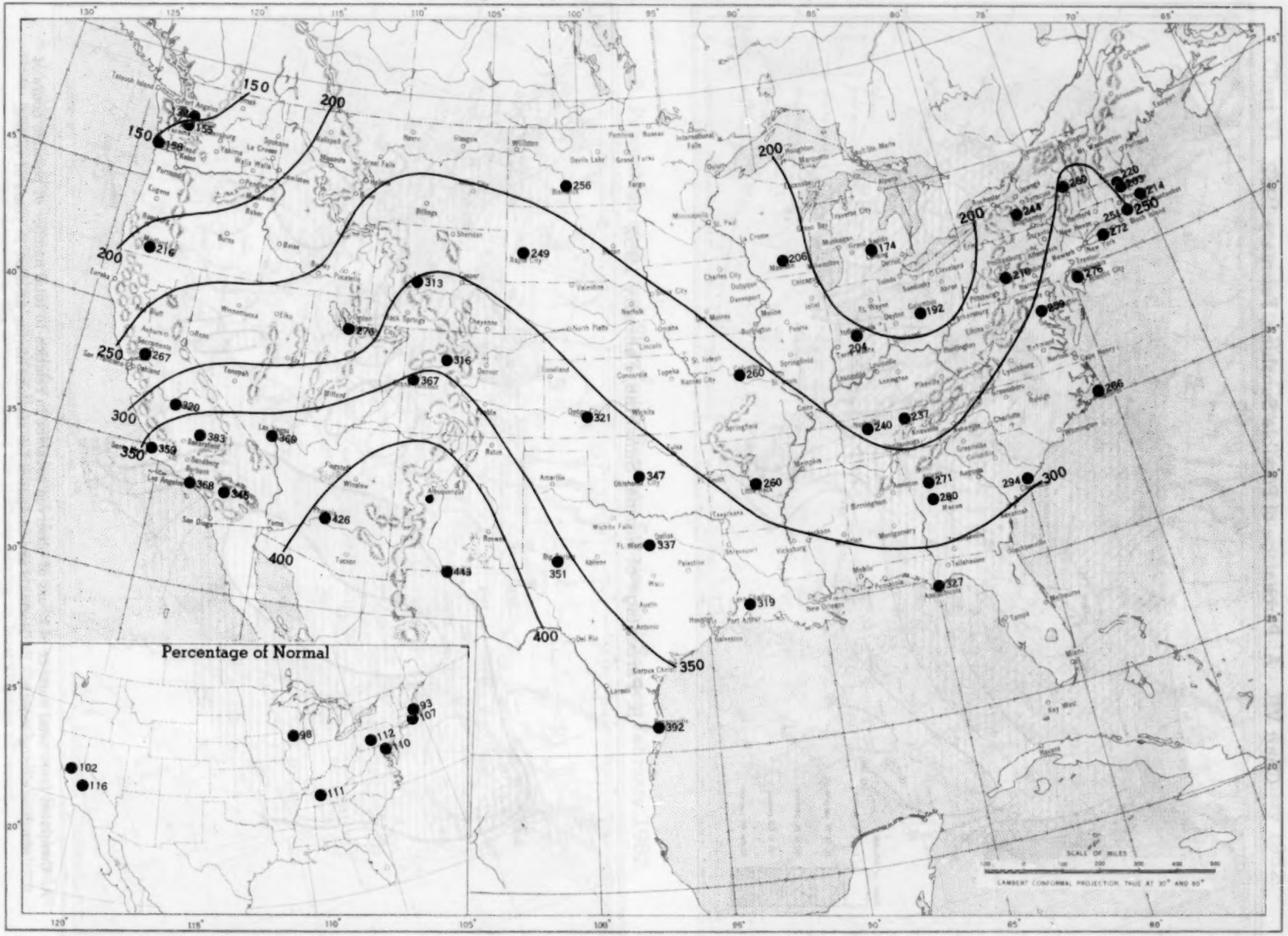
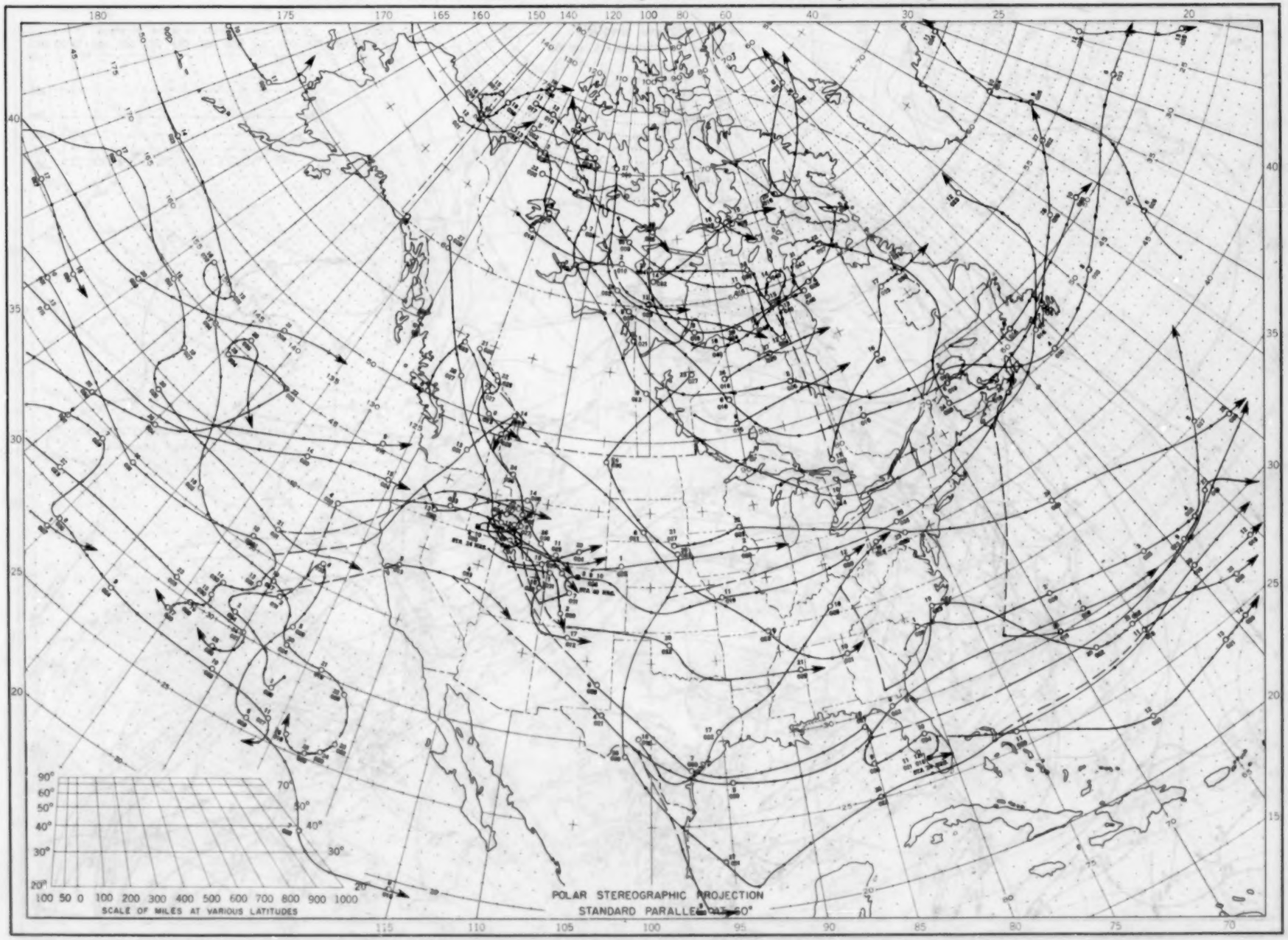


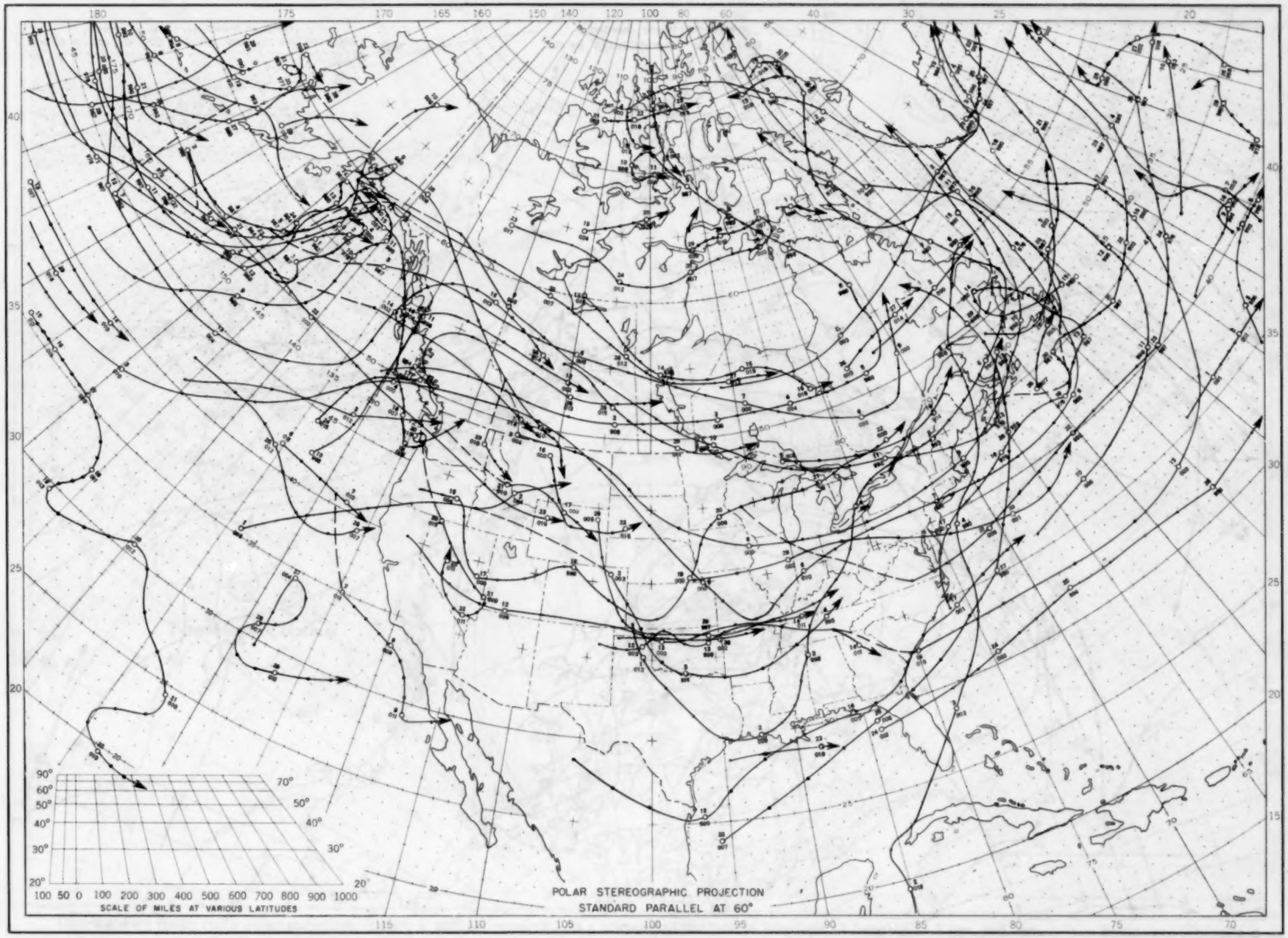
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates obtained from supplementary data for which limits of accuracy are wider than for those data shown. Normals are computed for stations having at least 9 years of record.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, February 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

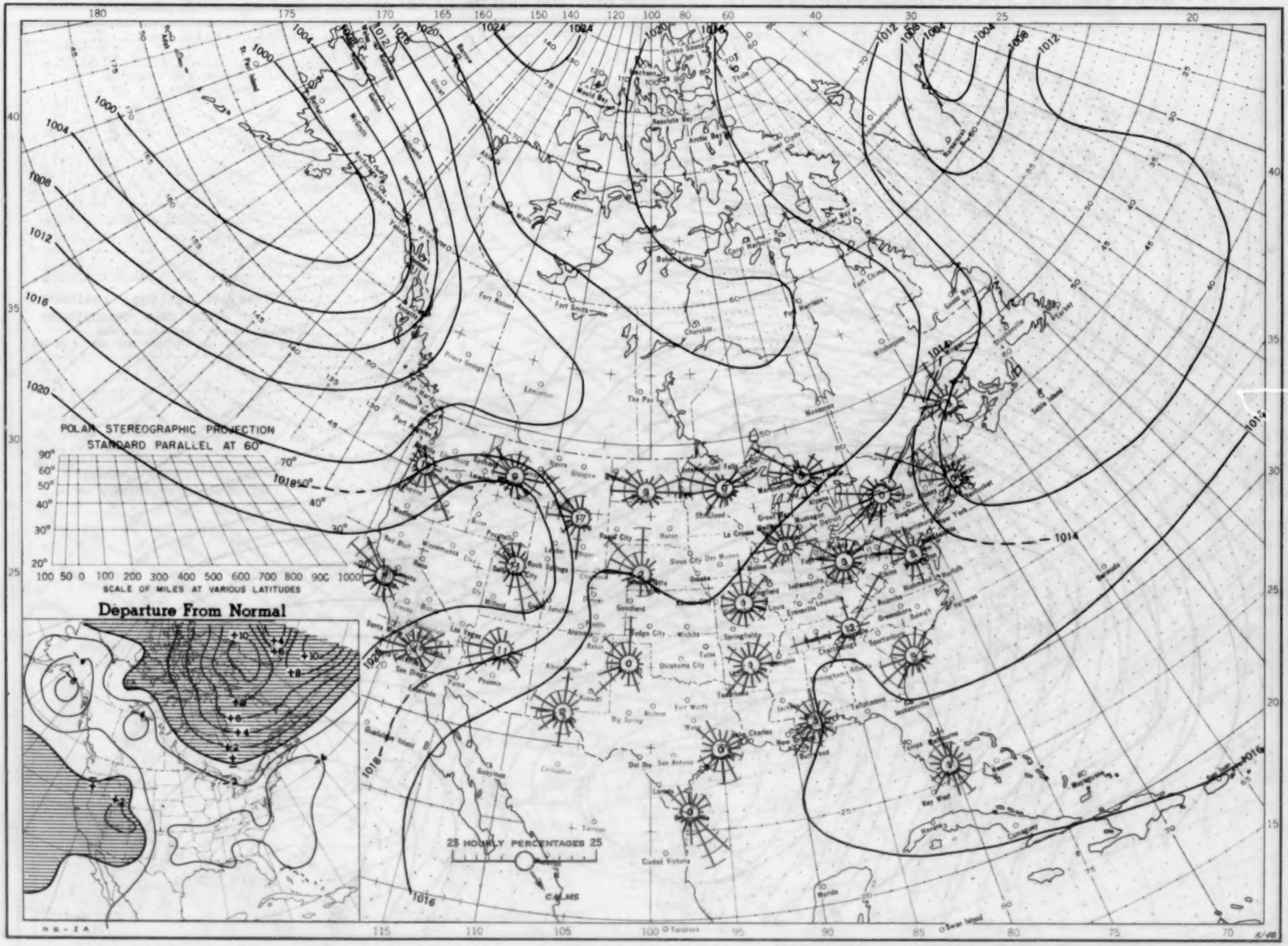
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, February 1952.


POLAR STEREOGRAPHIC PROJECTION
STANDARD PARALLEL AT 60°
SCALE OF MILES AT VARIOUS LATITUDES
100 50 0 100 200 300 400 500 600 700 800 900 1000

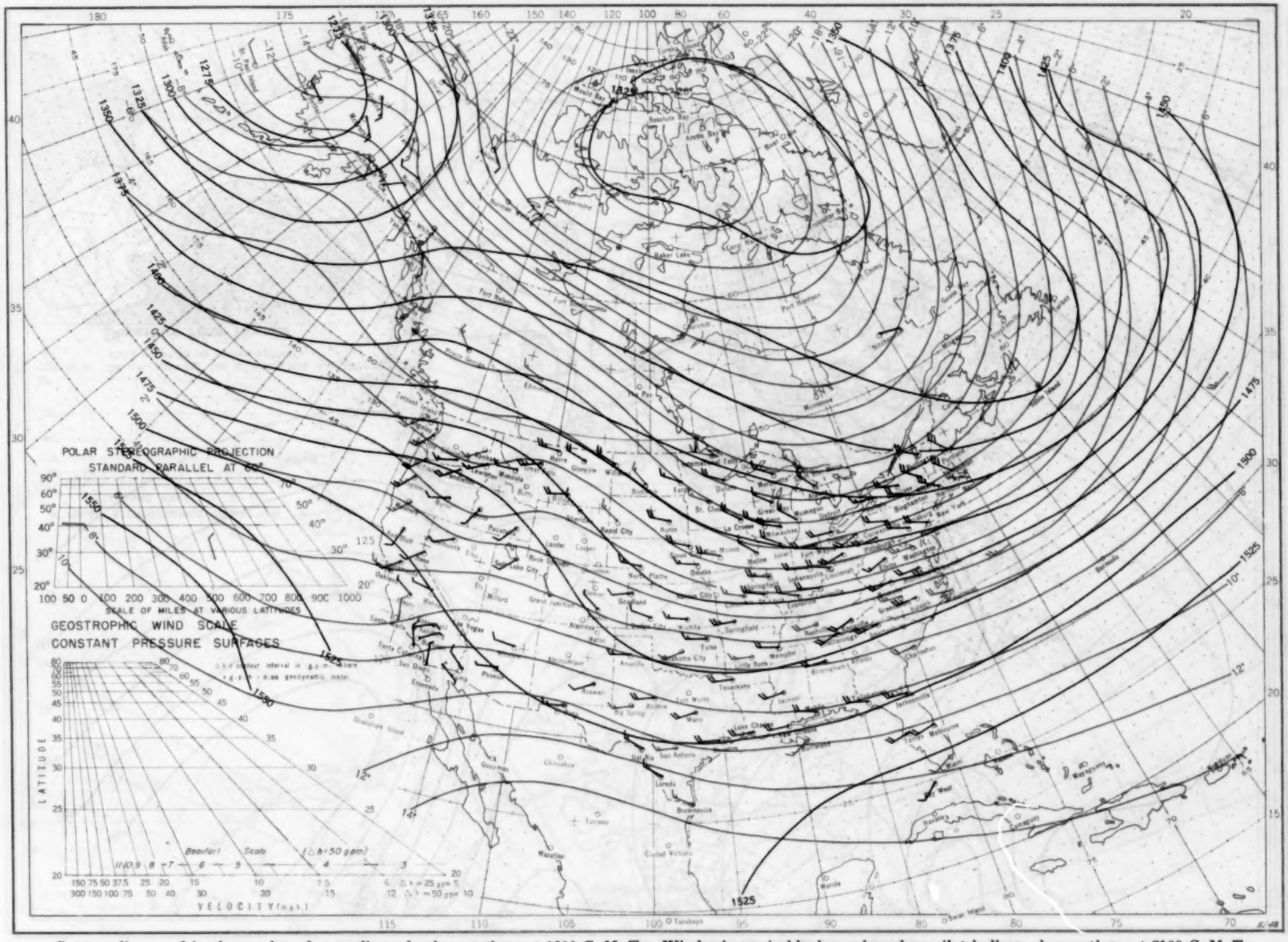
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, February 1952. Inset: Departure of Average Pressure (mb.) from Normal, February 1952.



Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

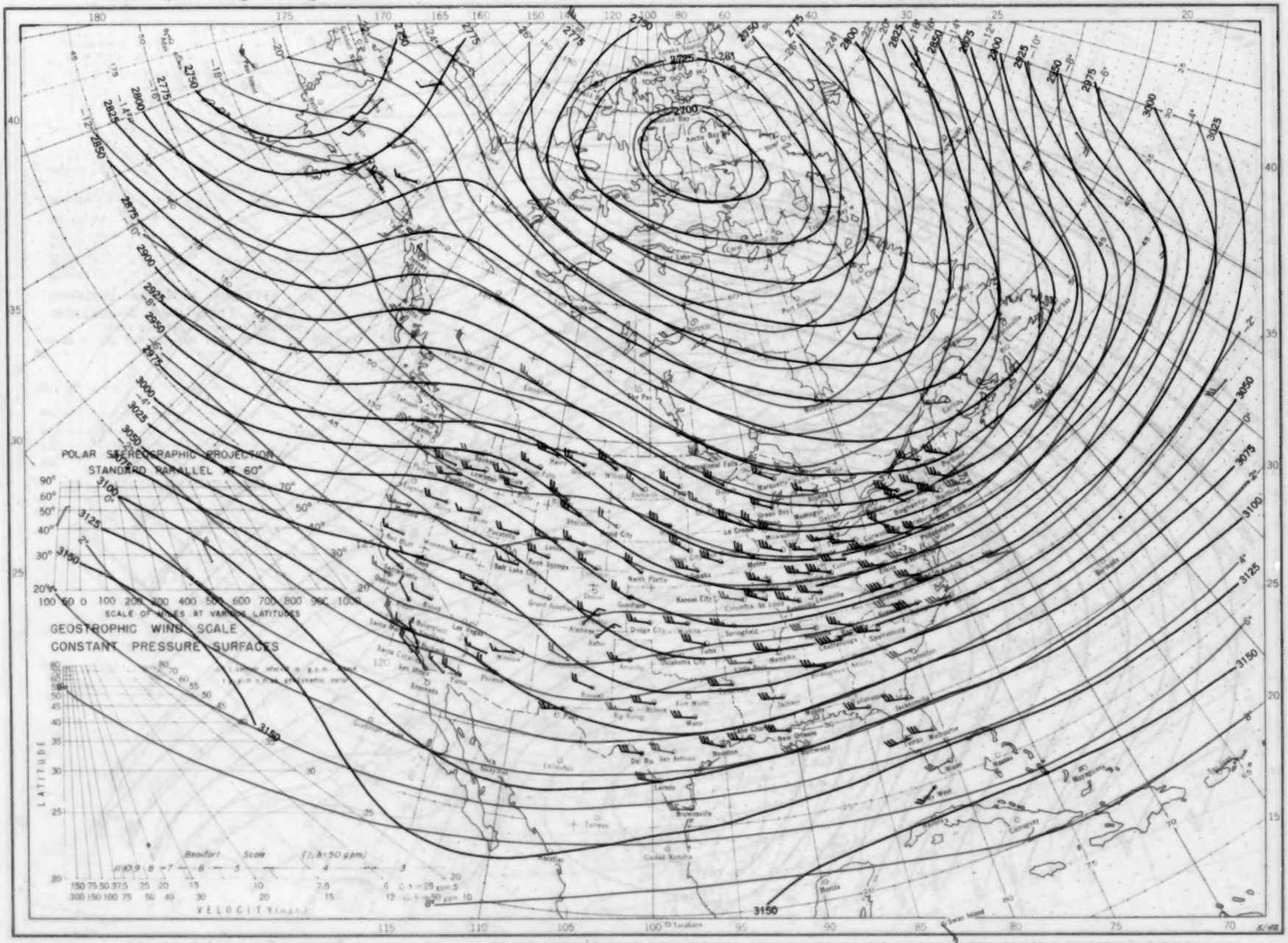
Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), February 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

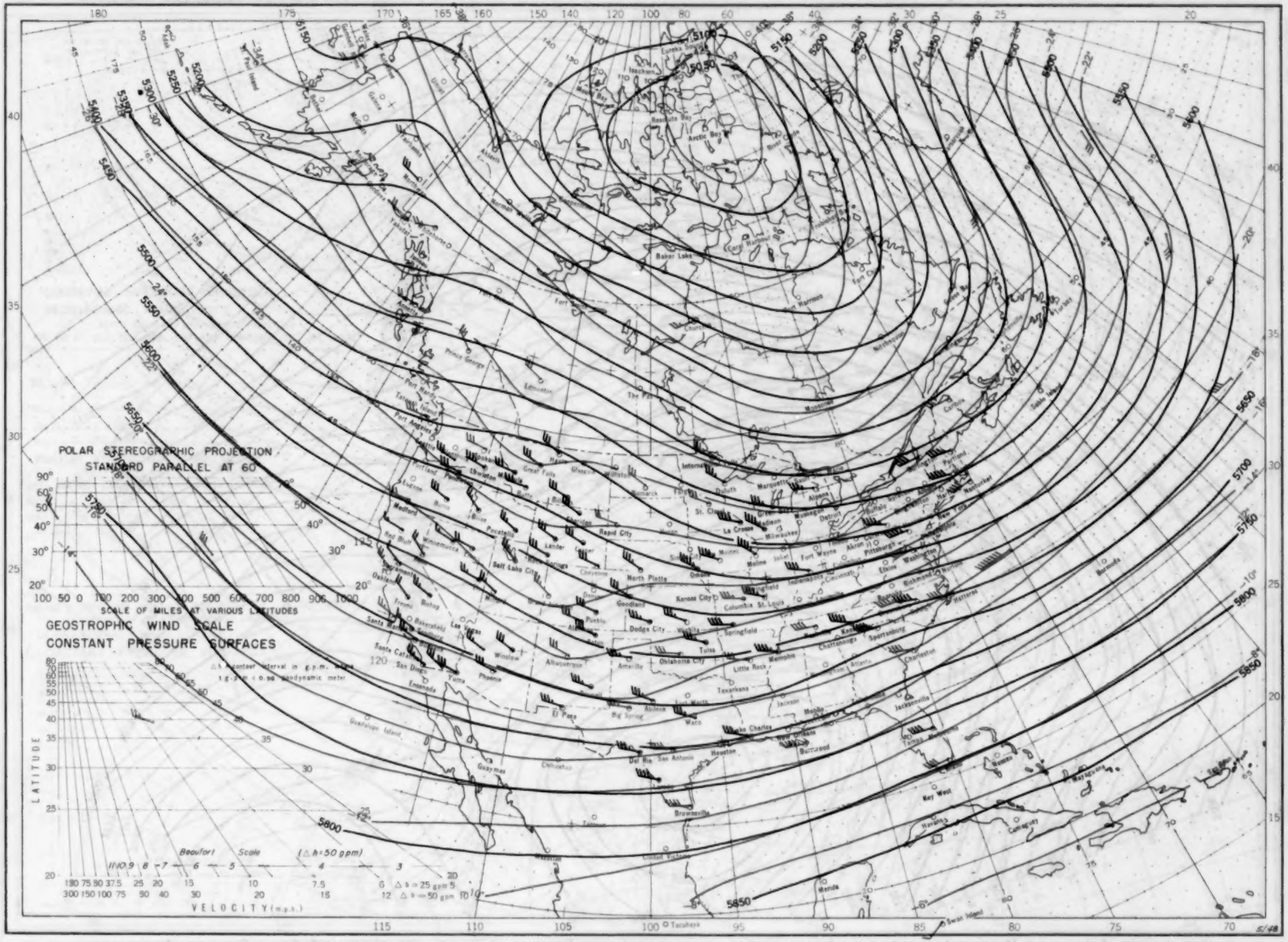
those shown in red are based on rawins taken at 0300 G. M. T.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), February 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T.

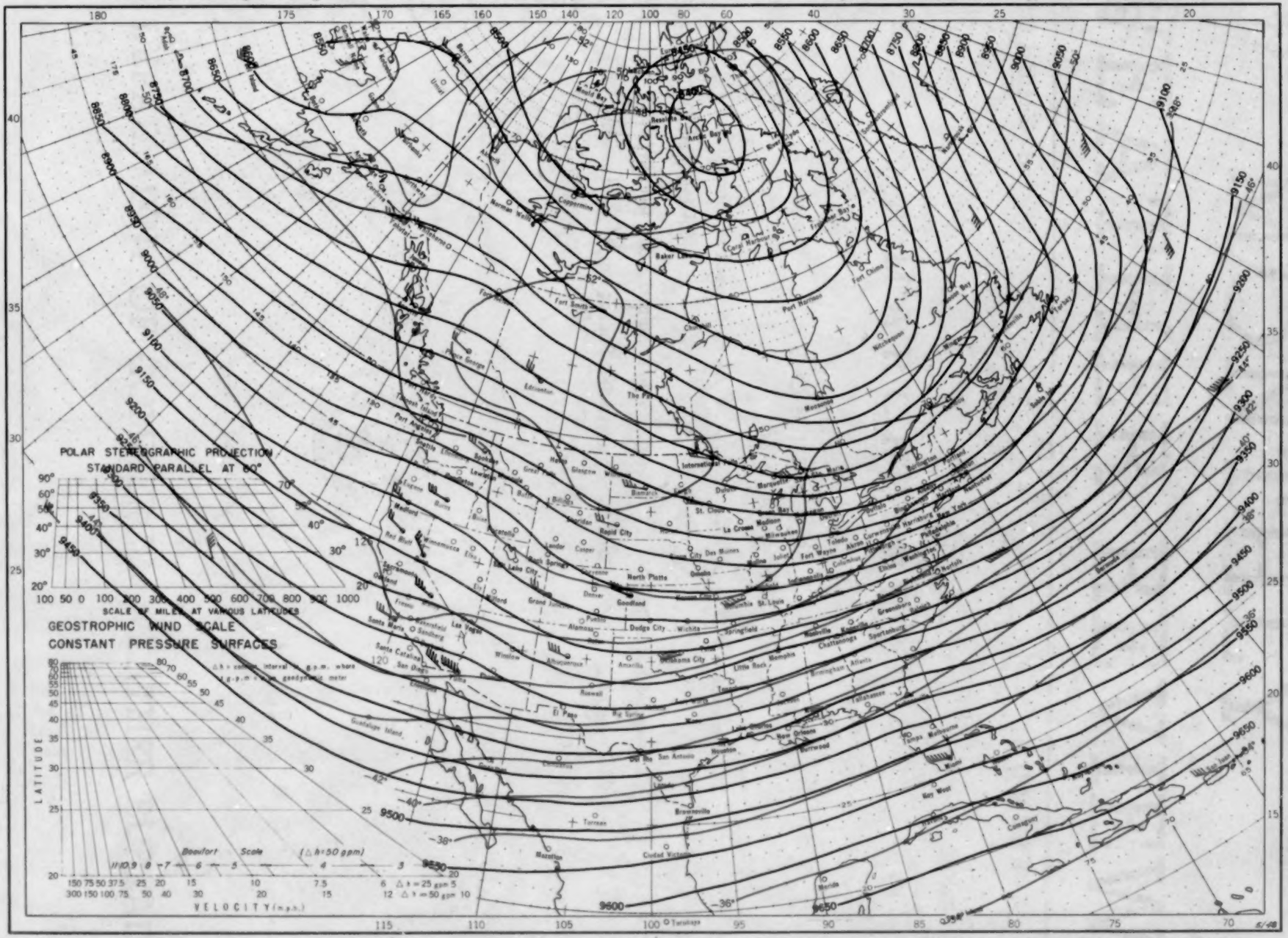
Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), February 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.

those shown in red are based on rawins at 0300 G. M. T.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), February 1952.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T.